AN INTRODUCTION TO BIOLOGY

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OXFORD
AT THE CLARENDON PRESS

Oxford University Press, Amen House, London E.C.4

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FIRST PUBLISHED 1938
REPRINTED 1939 (WITH CORRECTIONS)
1940, 1943, 1945, 1946, 1948, 1949, 1955, 1959

PRINTED IN GREAT BRITAIN

PREFACE

It is often asserted that, at the present stage of human development, biology has a special mission to fulfil in school education. It can awaken adolescent pupils to the relation between biological processes and their own lives, and provide them with a background for appreciating those processes in their true perspective. It can also stimulate interest in many of the wider issues now confronting humanity, which demand for their solution the application of biological knowledge to human affairs. Such problems as the effect on human populations of a differential birthrate, of mental disease, of increasing longevity combined with decreasing fertility, are troubling the minds of the thoughtful in most Western civilizations. In so far as the tendencies revealed are undesirable and therefore to be combated, they must be realized by the young, for ultimately only the young can change them.

Such are the often unformulated ideas which underlie the increasing demand for more biological teaching in the schools. Unfortunately, all too often biology is presented as so many isolated life-histories, so many field studies, so many facts of structure to be memorized for the purpose of passing an examination. Thus the pupil fails 'to see the wood for the trees', and the wider issues are neglected. The subject is often divided into botany and zoology, and little attempt is made to combine the two, although, as long ago as 1931, the panel of investigators then inquiring into the school-certificate examination urged the necessity of 'synthesizing the two into an organic whole' (see their report).

This book, which covers existing school-certificate syllabuses, embodies the attempt of a practising teacher to achieve that synthesis, and so to arrange the subject matter that those wider truths which can be learned from the study of biology gradually emerge. To do this it seemed essential to abandon the *type* method of presentation, and to make fundamental *activities*, such as feeding, respiration, growth, and reproduction, the central themes. Each section of the book deals with one

such activity; the study of structure is only carried far enough to illustrate function, and technical terms are very sparingly used. At the same time, the writer has not hesitated to introduce matter not demanded by the school-certificate examination when this seemed desirable to illustrate the various themes.

A secondary aim that has been kept in mind is to emphasize the experimental method, in view of its value in training precise and logical thought. The suggestions for experiments and exercises will, it is hoped, serve to demonstrate that general biology lends itself to experimental treatment in schools just as well as do the so-called 'exact' sciences. Stress is laid on the necessity for adequate controls in all forms of biological experimentation.

My sincere thanks are due to my son, F. E. S. Hatfield, M.A., M.B., for much valuable advice; to Dr. T. L. Prankerd, F.L.S., and to Miss B. Underhill, B.A., B.Sc. (Oxon.), for reading portions of the manuscript and for many helpful suggestions; to Miss E. Kirkwood for advice with the illustrations, many of which are original, and for permission to use two figures borrowed from her book *Plant Forms*; lastly, to my publishers for their patient care in the preparation of the book for publication.

E. J. H.

ACKNOWLEDGEMENTS

THANKS are due to the following bodies for permission to publish certain questions from their examination papers:

The *Oxford and Cambridge* Schools Examination Board.
The University of *Oxford* Local Examination Board.
The University of *Cambridge* Local Examination Board.
The University of *London* Matriculation and Schools Examination Council.
The *Northern Universities* Joint Matriculation Board.
The University of *Durham* Schools Examination Board.
The Central *Welsh* Schools Examination Board.

Also to the authors and publishers of the following works and journals for permission to reproduce, or utilize, figures.

L. A. Borradaile, *A Manual of Elementary Zoology* (Oxford University Press), for Figs. 30, 33, 34 (A and B), 40, 53, 85, 99, 132–9, and 162 (B); J. A. Campbell, *Readable Physiology and Hygiene* (G. Bell & Sons, Ltd.), for Fig. 77; A. R. Cushny, *Secretion of Urine* (Longmans, Green & Co., Ltd.), for Fig. 103; W. J. Dakin, *The Elements of General Zoology* (Oxford University Press), for Figs. 31–3, 39, 53, 61, 75–6, 92, 94, 165, and 167; E. J. Evans and H. G. Andrew, *A School Certificate Biology* (A. Wheaton & Co., Ltd.), for Fig. 162 (A); F. E. Fritch and E. J. Salisbury, *Elementary Studies in Plant Life* (G. Bell & Sons, Ltd.), for Fig. 117; P. Groom, *Elementary Botany* (G. Bell & Sons, Ltd.), for Fig. 154; J. B. S. Haldane and J. Huxley, *Animal Biology* (Clarendon Press), for Figs. 10 and 57; T. H. Huxley, *Lessons in Elementary Physiology* (Macmillan & Co., Ltd.), for Fig. 54; W. O. James, *Plant Physiology*, 3rd edition (Clarendon Press), for Figs. 20 and 28; M. A. Johnstone, *Physiology for Girls* (Blackie & Son, Ltd.), for Fig. 93; *Journal of Experimental Zoology*, vol. xxiv (Wistar Institute of Anatomy and Biology), for Fig. 124; *Journal of Heredity*, vol. 14 (American Genetic Association), for Fig. 123; E. J. G. Kirkwood, *Plant and Flower Forms* (Sidgwick & Jackson, Ltd.), for figs. 47 and 110; *Nouveau Petit Larousse Illustré* (Librairie Larousse, Paris), for Fig. 56; C. L. Laurie, *A Text-book of Elementary Botany* (Allman & Son), for Fig. 120; G. J. Romanes, *Darwin and After Darwin* (Longmans, Green & Co., Ltd.), for Fig. 168; E. A. Schafer, *Microscopic Anatomy* (Longmans, Green & Co., Ltd.), for Fig. 95 (B); E. Sharpley Schafer, *Essentials of Histology* (Longmans, Green & Co., Ltd.), for Fig. 63; A. E. Shipley and E. W. MacBride, *Zoology* (Cambridge University Press), for Figs. 35, 97, 105, 161, and 164 (B); E. P. Smith, *Experimental Biology* (Clarendon Press), for Figs. 24 and 158; M. A. Starr, *Organic and Functional Nervous Diseases* (Ballière, Tindall & Cox) for Fig. 54; E. Strasburger, T. Noll, and Others, *A Text-book of Botany* (Macmillan & Co., Ltd.), for Figs. 1, 114, and 141; J. Arthur Thomson, *Outline of Science*, vol. i (George Newnes, Ltd., and C. Arthur Pearson, Ltd.), for Figs. 62 and 164 (A); J. A. Thomson, *Outlines of Zoology* (Oxford University Press), for Figs. 84 and 91; T. W. Woodhead, *The Study of Plants* (Clarendon Press), for Figs. 16, 27, 29, and 110; F. J. Wyeth, *Elementary General Biology*, pt. i (G. Bell & Sons, Ltd.), for Fig. 34 (C); R. H. Yapp, *Botany* (Cambridge University Press), for Figs. 79 (B), 80, 116, and 146–7.

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NOTE TO TEACHERS

ALTHOUGH, for the reasons stated, the type system has been discarded in the writing of this book, this does not imply that it can be completely abandoned in the class-room. The biologist is peculiarly bound by times and seasons; frogs spawn in spring, snapdragons flower in summer, and such facts must influence all teaching schemes.

It is suggested, therefore, that the sequence of lessons must occasionally be broken, and such forms, as they occur, be first studied simply as *types*, without any further implication. The knowledge so acquired is then ready in the mind of the pupil, when it is needed to illustrate the wider theme.

The book is so arranged that sections can be interchanged should this seem desirable. The writer, for example, sometimes treats the subject of respiration early, before considering general feeding in detail, the experiments on respiration being simpler, in some ways, than those on animal nutrition.

PART I

INTRODUCTORY

CHAPTER I

INTRODUCTION TO THE HISTORY OF BIOLOGY

Biology (Gk. *bios*, life) is no new study. Men depend on plants and animals for food and have been driven to study them from very remote times. On the walls of caves primitive man has left us accurate drawings of animals long since extinct, which give evidence of careful observation.

Pastoral man subdued many animals to his service: buffaloes, sheep, goats, camels, and horses. He must have studied the plant world too, if only to discover which plants could most usefully be grown for food. Wheat, for example, has been under cultivation so long that only recently and after much careful research have we gained any knowledge about the wild plants from which it came.

Man, the hunter, whether ancient nomad or modern big-game shooter, is likewise a great naturalist, for he must know something about the habits of the creatures he pursues. It was the primitive hunter who tamed the dog and trained him to assist in the chase.

Finally, the ills that flesh is heir to are always with us, and all down the ages the medicine man and herbalist have collected facts about the working of the body, the symptoms of disease, and the use of plants in its cure. From all these sources civilized man inherited a vast store of useful knowledge; from all these roots sprang the science of biology, a science which originated in man's endeavour to satisfy his most pressing need—the need for food.

Speaking of the uncivilized tribes of central Africa among whom he travelled between 1860 and 1870, Winwood Reade says:

'Experiments are made on all kinds of plants with the view of

ascertaining what their qualities may be. The remarkable knowledge of herbs which savages possess; their skill in preparing decoctions which can act as medicines or as poisons, which can attract or repel wild animals, is not the result of instinct but of experiment, and this habit of searching for edibles, medicine, and poison becomes (that is, gradually develops into) the experimental spirit, the passion of inquiry which animates the lifetime of the scientific man.' (*The Martyrdom of Man*, by Winwood Reade.)

GREEK BIOLOGY. The true *science* of biology, the study of living things not for the sake of any 'useful' knowledge but merely for the joy of knowing something about them, probably began with the Greeks, and among the Greeks ARISTOTLE (384–322 B.C.) was the greatest biologist. He was interested in animals and described the lives of many of them with surprising accuracy. He even studied their development: for example, the growth of the chick within the egg. He discussed the functions of the organs of the body and was an enthusiastic naturalist.

'Every realm of Nature is marvellous.' 'We should venture on the study of every kind of animal without distaste, for each and all will reveal to us something natural and something beautiful.'

These sayings from Aristotle may serve as our guiding principle in the studies upon which we are now embarking.

Aristotle has been called the 'Father of Zoology', for he was more interested in animals than in plants. THEOPHRASTUS (327–287 B.C.), his favourite pupil, who succeeded him at the Lyceum (the great school which Aristotle founded), studied plants so intensively that he has been described as the 'Father of Botany'. Only a few of his many writings have survived to the present day; among these *The History of Plants* and *The Causes of Plants* are books containing much that is interesting to modern botanists. Many of his descriptions, those of germinating seeds, for example, are very accurate.

GREEK MEDICINE. The ancient Greeks loved learning and were real scientists. Great as was their work in pure biology, their work in medicine was perhaps even more important.

'Modern medicine', says Dr. Charles Singer, 'may truly be described as in essence a creation of the Greeks. The teaching of

Hippocrates and his school is the substantial basis of instruction in the wards of a modern hospital.' (*Greek Biology and Greek Medicine.*)

HIPPOCRATES (460–370 B.C.), the 'Father of Medicine', was one of the earliest, and perhaps the greatest, of these Greek physicians. Here is a part of the oath which his followers were required to swear:

'With purity and holiness will I pass my life and practise my art. . . . Into whatsoever houses I enter, I will go there for the benefit of the sick, and will abstain from every act of mischief and corruption. . . . Whatever in my professional practice I see or hear in the lives of men which ought not to be spoken of abroad, I will not divulge, deeming that on such matters we should be silent.'

The high standard of morality expressed by this oath has been maintained by the best medical men of all succeeding ages.

Many followed where Hippocrates had led. One of the last of these great physicians of antiquity was GALEN, born A.D. 131. His influence, even his doctrines, were destined to live on for over a thousand years and, when the revival of learning came to Europe and universities began to be founded, the text-books of Hippocrates and Galen were studied by all medical students. Even in the fifteenth and sixteenth centuries they were practically the only books available. The Greek civilization had long since passed away, but the works of the Greeks lived after them.

So that, when Troy had greatly passed
In one red, roaring fiery coal,
The courts the Grecians overcast
Became a city in the soul.

THE RISE OF MODERN BIOLOGY. How was it that, after so splendid a beginning, biology and medicine stood still for more than a thousand years? Why were text-books written before the birth of Christ still in use in the sixteenth century A.D.? Modern biological text-books are often 'out of date' almost before they are printed. What has caused this great change?

It has been due to the growth of an attitude of mind to which even the Greeks were largely strangers, an attitude of self-criticism to which they never attained. Great as they were,

it was not their custom to put their theories to the test of actual fact and actual experiment, however easy and obvious such experiments might be. They often described what *must* happen according to some ideal scheme of their own, instead of patiently endeavouring to find out what actually did happen. Even the great Aristotle fell into this error, and in the days after the fall of Greece this attitude of mind became fixed and almost universal.

The beautiful *herbals* made by the medieval monks, for example, were illustrated by pictures which were carefully copied from earlier ones, becoming more inaccurate with every repetition. Nobody seems to have thought of looking at the actual plants, although they were probably growing in the monastery garden. The same spirit pervaded the whole intellectual life of that era. Whatever a great man had said *must* be true, and it was quite wrong to challenge it. It was not until this attitude had changed; until men were ready to question authority where necessary; until they had devised methods of putting their theories to the test, so that their knowledge became more accurate, that modern science was born.

'Science', a famous modern physicist has said, 'can only be created by correct thinking.'

The scientist must learn to check all his theories by accurate observation and careful experiment, and unhesitatingly to discard every idea which does not fit the facts as known.

'Experiment', said Leonardo da Vinci (1452–1519), 'is the interpreter of nature. Experiments never deceive. It is our judgement which sometimes deceives itself because it expects results which experiment refuses. We must consult experiment, varying the circumstances until we have deduced general rules, for experiment alone can furnish reliable rules.'

Only when men had learned this lesson did they become scientists; when once they had learned it they went rapidly ahead.

'Why did the pace suddenly quicken in the sixteenth and seventeenth centuries? At the close of the Middle Ages a new mentality

discloses itself. . . . Although in the year 1500 Europe knew less than Archimedes, who died in the year 212 B.C., yet in the year 1700, Newton's 'Principia' had been written and the world was well started on the modern epoch.' (Whitehead, *Science and the Modern World.*)

PHILOSOPHERS ENCOURAGE THIS SCIENTIFIC SPIRIT OF INQUIRY. In the late sixteenth and early seventeenth centuries many great thinkers were explaining the new methods and showing men how to obtain more accurate knowledge. FRANCIS BACON (1561–1646), the great English Chancellor and politician, and RÉNÉ DESCARTES (1596–1650), the famous French mathematician, were among the most renowned. They both did much to inculcate new habits of thought and hence to form the 'modern' mentality. At first the way was not easy and progress was slow; there was tremendous prejudice to be overcome.

GALILEO (1564–1642) was one of the first scientists produced by the new movement. Even as a student he earned the nickname of 'The Wrangler' by his tendency to argue, his habit of questioning that ancient wisdom which was held to be quite infallible. One story of his early career has often been told, and, although the evidence on which it rests is not very sound, we give it since it illustrates so aptly the new method of attacking scientific problems.

Aristotle seems to have thought that bodies fall at rates which are proportional to their weights. Galileo argued that weight would have no influence on the rate of fall, and is reputed to have tested this idea by dropping two unequal weights from the top of the Leaning Tower of Pisa.

Although the result of this experiment supported his theory he did not convince his opponents, and all through his life he encountered considerable opposition. Yet 'great is truth and will prevail'; the new ideas continually gained ground. NEWTON was born in the year Galileo died (1642); gradually the new spirit of inquiry spread, the medieval world of fixed ideas was left behind, and the modern epoch began. For the world to-day is a scientific world; the attitude of the scientist pervades all our thought; even our political and historical ideas are subject to the same influence.

Much has been accomplished since that rebirth in the sixteenth century, but far more remains to be done. Scientific discovery, and above all biological discovery, is only in its infancy. The world has adopted the scientific attitude of mind, but it has not yet adopted a biological one. Many believe that this must be man's next great step forward. What such an attitude might do for him will be clearer when you are at the end of the course which you are now only just beginning.

> Rich labour is the struggle to be wise,
> While we make sure the struggle cannot cease.
> Else better were it, in some bower of peace,
> Slothfully to swing, contending with the flies.
>
> (George Meredith.)

'Have the past struggles succeeded? What has succeeded? Yourself? Your Nation? Nature? Now understand me well—it is provided in the essence of things that from any fruition of success, no matter what, shall come forth something to make a greater struggle necessary.' (Walt Whitman.)

TWO GREAT BIOLOGICAL DISCOVERIES. Before we leave this short outline of the early history of our subject, let us look at two great discoveries, both among the first-fruits of the new methods of inquiry and experiment, and both of great importance in the history of biology.

I. *The Discovery of the Circulation of the Blood.* This discovery was mainly due to WILLIAM HARVEY (1578–1657), physician to the court of Charles I. Before his time ideas on this subject were extraordinarily confused. Men still held fast to Galen's doctrine that the blood as it passes through various organs of the body becomes mixed with 'spirits'—natural, animal, and vital; and although they knew that the blood moves in the blood-vessels they had no picture of a continuous circulation, but thought, for example, that in the veins it ebbed and flowed, backwards and forwards.

Harvey was able to tell a very different story, having discovered the true facts by patient experiments and dissections. He proved that

> 'The blood in the animal body is impelled in a circle, and is in a state of ceaseless motion. . . . This is the actual function which the

heart performs by means of its pulse, and this is the sole and only end of the motion and contraction of the heart.' (*The Motion of the Blood and Heart*, by William Harvey. First printed and published in Latin at Frankfort in 1628.)

Harvey dedicated his book to 'The most illustrious and indomitable Prince Charles', and modern readers will notice with astonishment how carefully he defends himself, in his preface, against the charge of 'belittling the ancients'.

'I do not think it right or proper to take from the ancients any honour that is their due. . . . I avow myself the partisan of truth alone', he said in the letter which he sent with a copy of his book to the President of the Royal College of Physicians. Yet, in spite of his clear and striking arguments, in spite of the accurate experiments which make his book 'Le plus beau livre de la physiologie', as a French critic said, Harvey had to suffer the fate of all pioneers.

'I have heard him say that, after his book was out, he fell mightily in his practice and 'twas believed by the vulgar that he was crack-brained, and all the "physitians" were against him', says one of his friends.

But Harvey lived to see his discoveries accepted, and this knowledge of the circulation of the blood and of the true function of the heart led to many new discoveries. So began the modern science of *physiology*, one of the most important branches of both biology and medicine.

II. *The Microscope and the Discovery of Cells.* Another early outcome of this new method of inquiry was the invention of both the telescope and the microscope. Galileo is said to have been the first to use a microscope for biological observation (in 1634) and very soon there were microscopists all over Europe revealing to men a world of minute structure of which they had heretofore been quite ignorant.

Robert Hooke (1636–1703), who was the first secretary of the Royal Society (a scientific society which, founded in 1660, is still famous), examined many objects with his microscope, and in 1665 published some beautiful descriptions and drawings of them in his book *Micrographia*. Among these were a

sketch and a graphic description of a thin slice of bottle cork (cp. Fig. 1).

'I could', he says, 'exceeding plain perceive it to be all perforated and porous, much like a honeycomb but that the pores were not regular. . . . It had very little solid substance in comparison of the empty cavity that was contained between, as does most manifestly appear in the Figure.'



FIG. 1. Portion of Hooke's drawing of the 'schematisme' and texture of cork

Hooke called these structures cells. This name has survived to the present day, and the study of cells, *cytology*, is a very important branch of modern biology, for cells are the unit structures of which the bodies of all plants and animals consist. Knowledge of their nature has advanced very rapidly since 1665, especially in the last hundred years, and, although we keep the name, modern biologists do not mean quite the same thing as Hooke did by this term. This will be made clear in a subsequent chapter.

QUESTIONS ON CHAPTER I

1. Write a short account of the life and work of any famous biologist.
2. Describe the change in men's attitude to knowledge which made the rise of modern science possible. Illustrate your answer by reference to definite examples.
3. What do you know about the biological work of the Greeks?
4. Give an account of the life and work of William Harvey, and explain, as far as you can, why his discoveries were of such importance.
5. Give familiar quotations from Chaucer, Milton, Shakespeare, or any other author who wrote before the eighteenth century, which illustrate their ideas about the workings of the human body.

SOME SUGGESTIONS FOR FURTHER READING

Simple.

1. *A Short History of Natural Science.* Arabella B. Buckley. (Published 1879.)
2. *Six Great Biologists.* Sir J. A. Thomson. (Methuen.)
3. *Louis Pasteur,* by Hallock. (D. G. Heath & Co.)
4. *Story Lives of Men of Science.* F. J. Rowbotham. (Wells, Gardner, Darton & Co. Ltd.)

More advanced.

1. *Greek Biology and Greek Medicine.* Dr. C. Singer. (Clarendon Press.)
2. *The Discovery of the Circulation of the Blood.* Dr. C. Singer. ('Classics of Scientific Method': Bell.)
3. *The Motion of the Heart and Blood.* William Harvey. (Reprint: Everyman's Library, Dent.)
4. *Pioneers of Progress: Galileo.* W. W. Bryant. (Society for Promoting Christian Knowledge.)
5. *The Legacy of Greece*
6. *The Legacy of Rome* } (The Clarendon Press.)
7. *Biology and Its Makers.* Locy. (Bell.)
8. *Growth of Biology.* Locy. (Bell.)
9. *A Short History of Botany.* Harvey Gibson. (Black.)
10. *The Early Naturalists, their Lives and Work.* L. C. Miall. (Macmillan.)
11. *Zoo Cavalcade: An Account of the Evolution of the Zoo from the Time of the Ancient Egyptians.* E. C. Boulenger. (Dent.)
12. *The Torch Bearers,* vol. ii. A. Noyes. (Blackwood.)

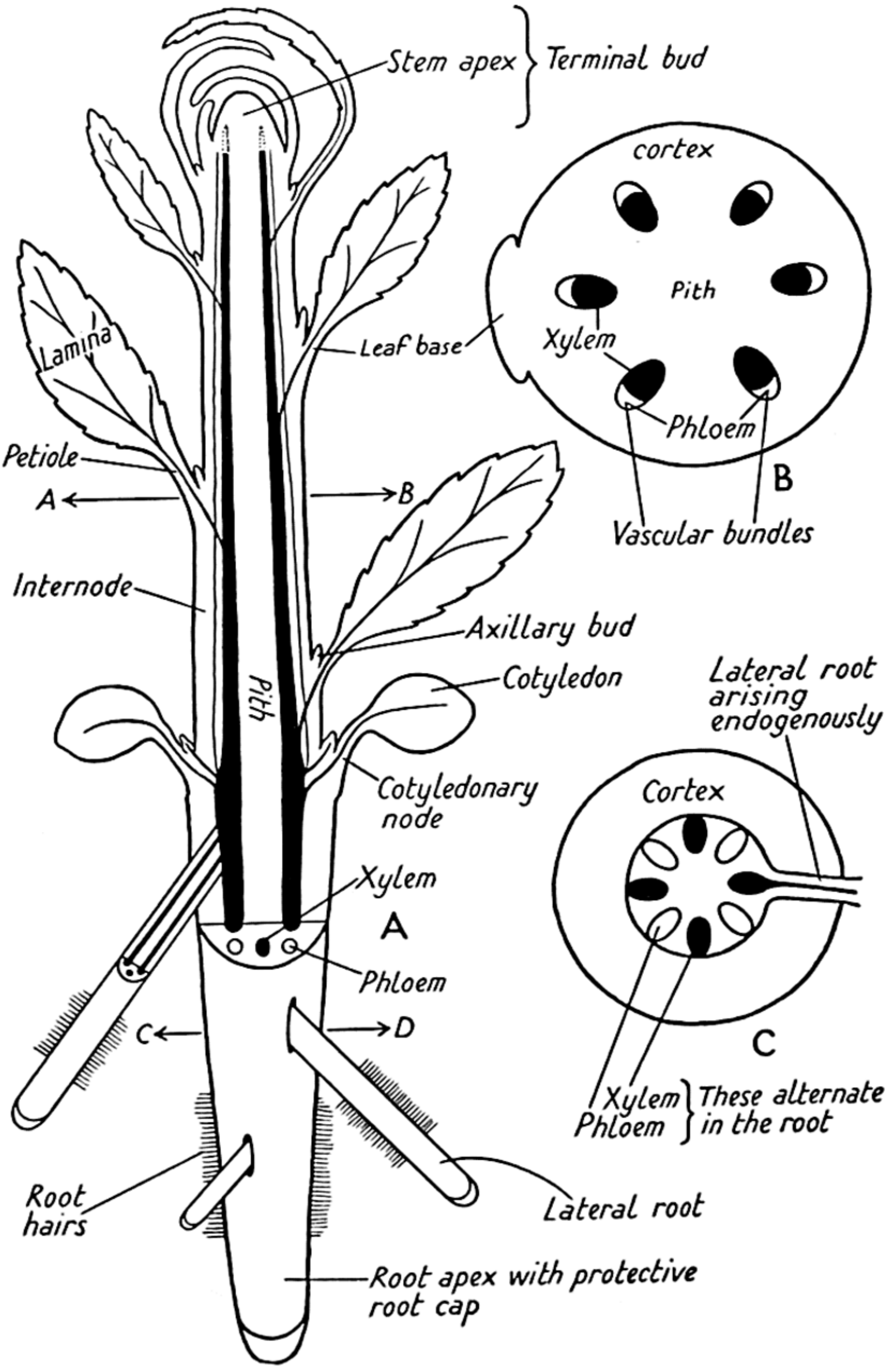


Fig. 2. **For description see foot of page 19**

CHAPTER II

THE STRUCTURE OF LIVING ORGANISMS. CELLS

'The body fitly framed and knit together.'—Eph. iv. 16 (R.V.)

We turn now to study the plants and animals of to-day about which we all know something already. If you have had any lessons in nature study you should revise what you have learned. Let us begin by examining a flowering plant.

Exercise. Examine and make sketches of a few flowering plants, such as a sunflower (preferably young), wallflower, or buttercup. Compare what you find with the plan given in Fig. 2.

Cut thin slices of the root and stem of each specimen (for method cp. p. 92), and try to discover something of the internal as well as the external structure. You will find it easier to do this if you stain your slices (sections) with aniline sulphate or eosin and hold them, mounted on a glass slide (cp. p. 25), up to the light.

THE TYPICAL FLOWERING PLANT. Fig. 2 illustrates the fundamental plan underlying the structure of every flowering plant. The shoot system usually grows upwards towards the light; it consists of stems each ending in a bud (the terminal bud) and bearing leaves at the nodes. In the axil of every leaf we find an axillary bud; when one of these grows it produces a branch stem which repeats the structure of the main axis. In due season this shoot system also gives rise to flowers, fruits, and seeds. (Confirm these statements from your specimens.)

The root consists of a number of tapering cylinders all very similar in form. Near the tip of each is a region covered with fine root-hairs (cp. Fig. 19). Often, as in the figure, there is a main root with lateral branches (a tap-root system); sometimes, however, the root consists of many branches of approximately equal size (a fibrous root system).

Internally the flowering plant also exhibits a definite struc-

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DESCRIPTION OF FIG. 2. The general structure of a flowering plant. A. Longitudinal section. B. Transverse section of the stem at *AB* (of A). C. Transverse section of root at *CD* (of A)

ture. In the centre of the stem is a conspicuous pith. This is surrounded by the conducting tissue, seen in a transverse section of a young stem as a ring of vascular strands (or bundles) separated from each other by rays of soft tissue, called medullary rays. These strands, as the figure shows, pass out into the leaves, forming the veins. Outside this conducting tissue is the cortex, and outside all a protective layer termed the epidermis.

In the root a very similar arrangement is shown by our sections. We notice epidermis, cortex, and conducting tissue; the last is usually more centrally placed than in the stem, so that there is often very little pith. Branch roots are seen to originate inside the parent root; as they grow, they push their way through the cortex to the outside. All these facts can be confirmed by examining any flowering plant with a lens or even with the naked eye; the structures referred to will be described in greater detail later (cp. Chapter IX).

THE TYPICAL MAMMALIAN ANIMAL. Let us now examine an animal to observe something of its structure, beginning with one rather like ourselves, e.g. a rabbit.

Exercise. Study the external structure of the rabbit and compare it with that of any other four-footed creatures that are available. Look, too, at pickled dissections, charts, and mounted skeletons of such animals, so as to obtain some idea of their internal organization.

The rabbit is an alert, sensitive creature, watching our actions and making various responses to them. It can move very quickly, especially when alarmed. This power of locomotion (movement from place to place) is one of the most striking differences between the typical animal and the plant. The rabbit grows hungry and seeks food to satisfy its hunger, as we do; it is a vegetarian, feeding chiefly on leaves. It wakes and sleeps, works, rests, and plays, and soon learns to recognize both friends and foes. Compare its body with your own. It consists of head, neck, trunk, tail, and two pairs of limbs. On the head are two eyes, a nose with two nostrils, a mouth with lips, teeth, tongue, and long sensitive hairs (vibrissae). Each limb has divisions corresponding to our own thigh, calf,

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ankle, and foot; the feet end in digits each bearing a claw, even as in man the limbs end in fingers or toes with nails.

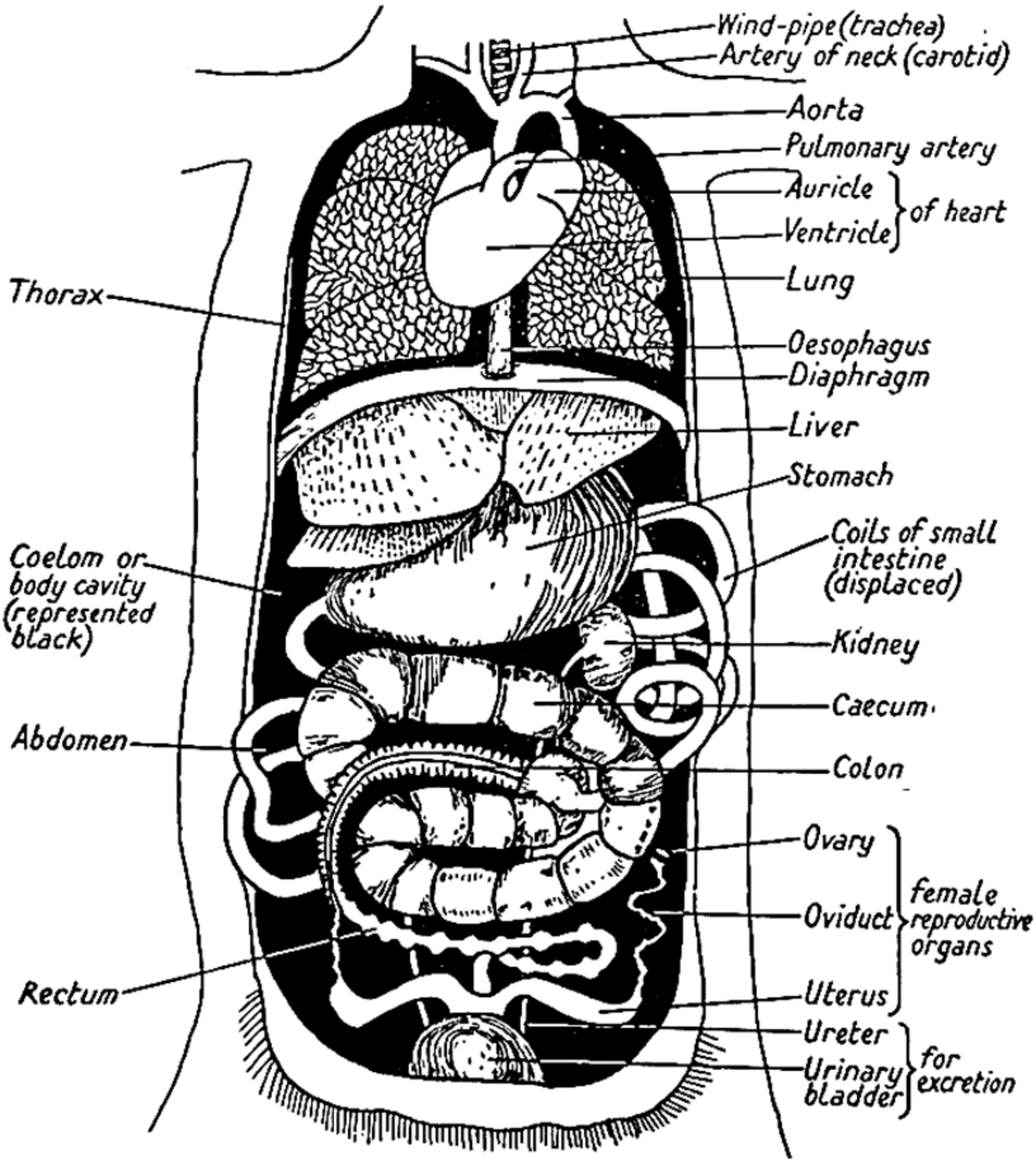


FIG. 3. Rabbit opened to display the principal organs (somewhat diagrammatic)

The rabbit has five digits on each fore-foot; on the hind limb only four (cp. p. 417).

Internally the body is supported by a bony framework or skeleton, as ours is (cp. Fig. 4); to this are attached the muscles by which the creature moves. Some parts of the skeleton, e.g.

the backbone, the skull, the ribs, can be distinctly felt through the skin. Inside the trunk is a large space, the body cavity or coelom, in which many of the more important organs of the body lie (cp. Fig. 3). In ourselves (cp. Fig. 4), in the rabbit, indeed in all mammals,[1] this space is divided by a transverse partition, the diaphragm, into the chest cavity or thorax and the abdomen. Heart and lungs (two) lie in the thorax, the walls of which are strengthened on each side by the ribs. The abdomen contains such important organs as the stomach and intestine, concerned with the digestion of food; the liver, pancreas, and spleen; the kidneys (two), ureters, and urinary bladder for excreting waste substances; the reproductive organs, &c. These facts are illustrated in Figs. 3 and 4.

CLASSIFICATION OF PLANTS AND ANIMALS. This preliminary study has illustrated an important biological fact. There is a definite plan of structure which goes right through the whole group of flowering plants, however much the individual types (species) differ in general appearance and in the details of their structure. Similarly all mammals have many features in common, and some of these structures are found not only in the mammals but in all vertebrates.

We use this knowledge to classify living organisms into definite groups (or *phyla*), each group having its own characteristic features which clearly distinguish it from all other groups. Vertebrates, Arthropods (jointed-legged animals such as crabs, insects, spiders, &c.), Worms, Molluscs (creatures with shells, such as snails, oysters, &c.) are familiar animal groups; Flowering plants, Ferns, Mosses, Fungi, some of the more important sub-divisions of the plants. (Cp. Appendix I.)

Exercise. Examine a collection of birds, of insects, of brown seaweeds, of toadstools, and make lists of those features of external structure which seem to be characteristic of each of these groups.

CELLS THE UNIT OF STRUCTURE. Flowering plants are the most highly organized group of plants, mammals the highest

[1] Mammals are vertebrate animals whose bodies are more or less covered with hair, and who nourish their young with milk.

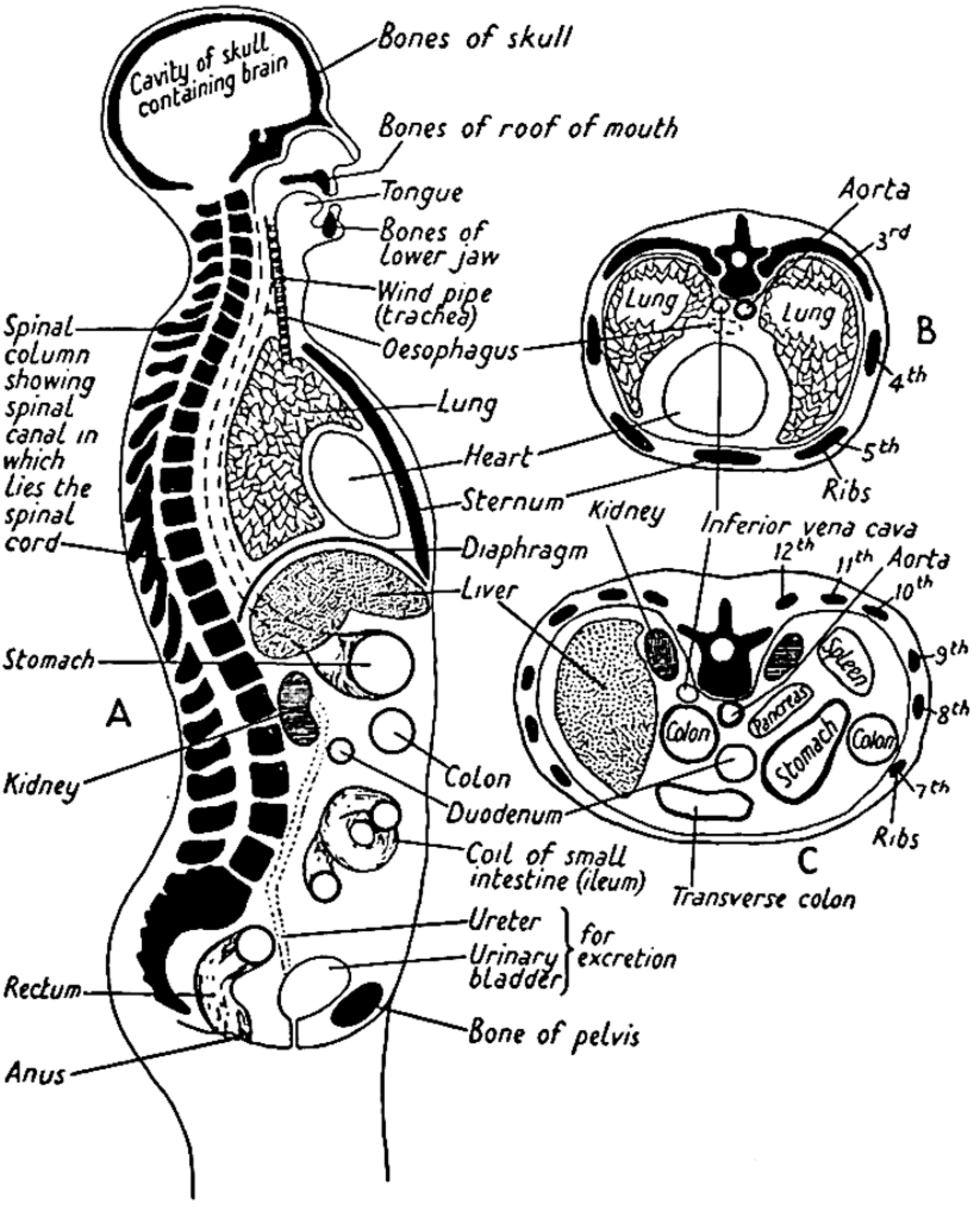
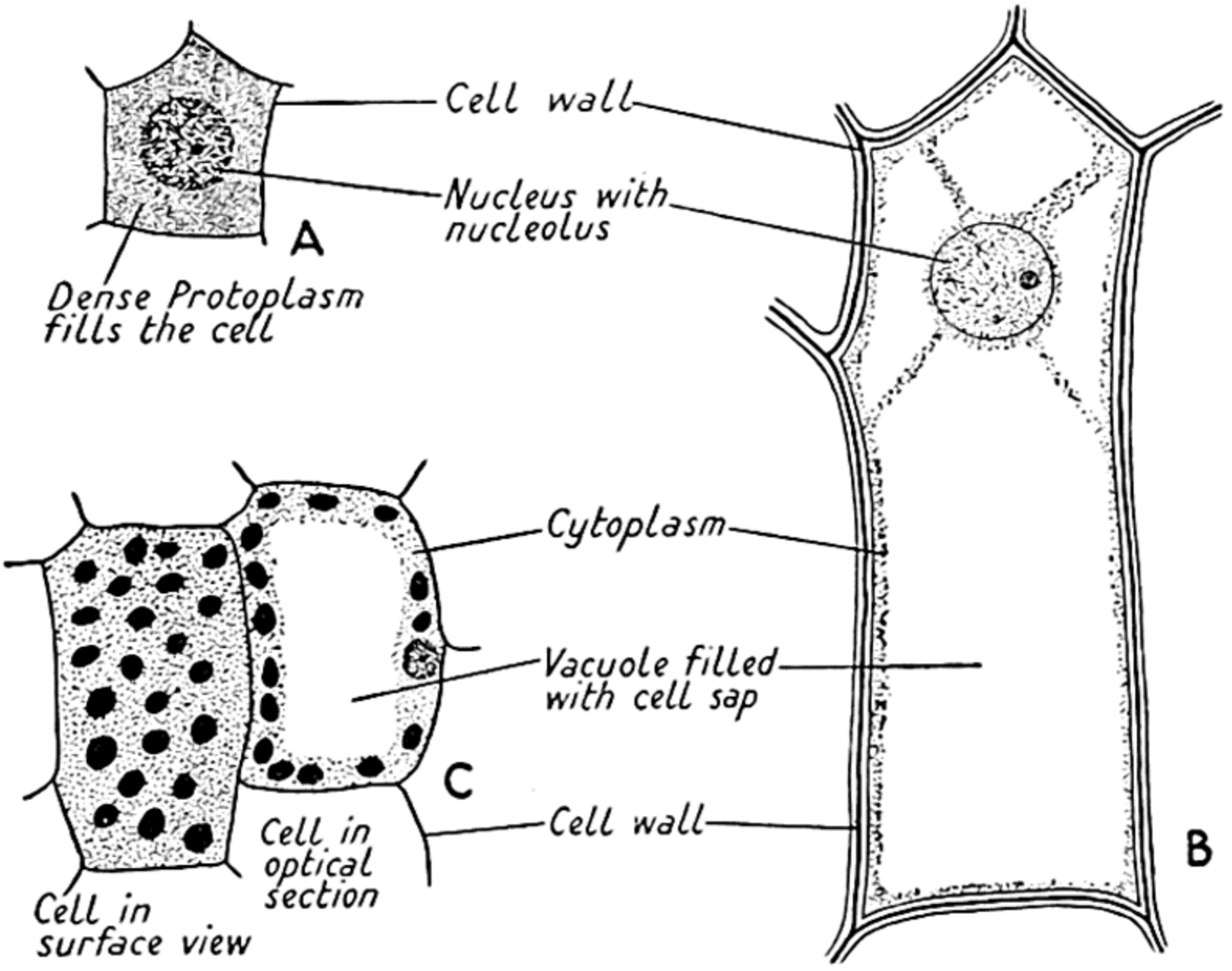


FIG. 4. **A.** Longitudinal section of the human body, showing certain organs (e.g. lungs, kidneys) which would not appear in a true median section. **B.** Transverse section above the diaphragm. **C.** Transverse section below the diaphragm. All sections very diagrammatic



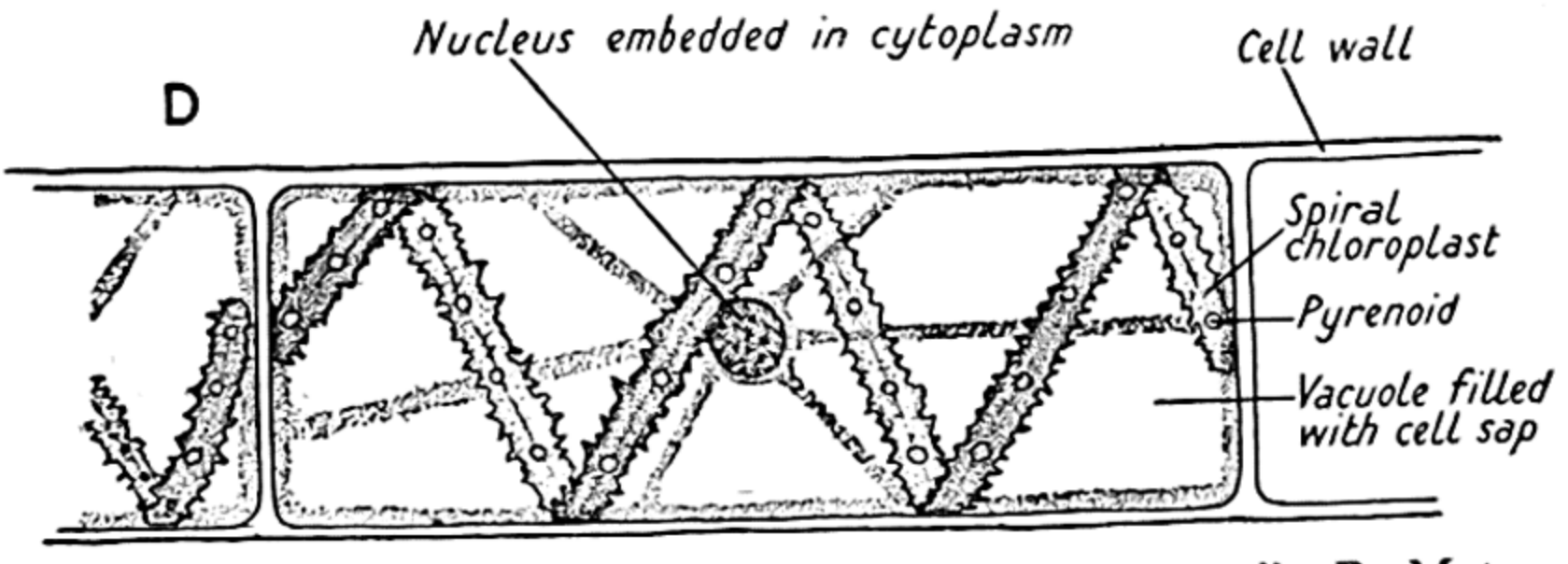


FIG. 5. PLANT CELLS. **A.** Young (meristematic) plant cell. **B.** Mature colourless cell from scale leaf of onion bulb. **C.** Cells from green leaf of Canadian water-weed. **D.** Green cell of Spirogyra. (All diagrammatic and highly magnified)

animals; many living organisms are much simpler in structure. Yet, under all such differences, they have one feature in common. Their bodies are made up of the units which Hooke (cp. p. 16) called cells. In some creatures the body consists of one such unit only, i.e. they are unicellular, and can only be examined with a microscope. Those we see around us are all multicellular; the total number of cells in the human body is of the order of 1,000,000,000,000,000.

CELL STRUCTURE. Although Hooke gave the name 'cells' in 1667 to the units of which all living bodies consist, two hundred years were to elapse before any clear idea was obtained of their nature. Let us examine a few cells to see what we can discover about them for ourselves.

Exercise. Strip off a fragment of skin from the scale leaf of an onion bulb. Have ready a glass microscope slide on which there is a small drop of water; spread out a tiny fragment of the skin in this water and cover it carefully with a clean cover-slip. Let this down gently so that no air is enclosed.

This operation is called 'mounting the object'. It is usual to mount all objects for microscopic study in some fluid (water, glycerine, Canada balsam, &c.). Make a similar preparation on a second slide, adding a drop of iodine solution to the water in which the skin is mounted.

Examine these preparations with a lens and if possible with a microscope or microprojector.

We find that this skin is formed of a number of similar structures; these are the cells. Each somewhat resembles a narrow oblong box in shape and is bounded by a *cell-wall* formed mainly of a material called cellulose. These walls are the part of the cell that Hooke saw; they are not alive and may remain long after the living parts of the cell have vanished; indeed, all cotton fabrics are woven from the walls of dead plant cells. Inside the wall is the living part of the cell, the *protoplasm* (cp. Fig. 5), a colourless substance which we shall examine more fully later. We notice, first of all, a dense spherical body made of a special protoplasm (nucleoplasm); it is the *nucleus*, and is clearly marked off from the rest of the cell contents by its specialized outer surface, the nuclear

membrane. (Within the nucleus one or more smaller structures, the nucleoli, are often visible.) The rest of the protoplasm is known as the *cytoplasm*. It does not fill the whole of a mature cell, but always forms a thin layer (often very difficult to see) in close contact with the cell-wall (cp. Fig. 5 B, D). The nucleus may be embedded in this, or may be centrally placed, in which case it is surrounded by a little protoplasm, while living strands of the same material extend across the space (*vacuole*) which occupies the middle of the cell (cp. Fig. 5 B, D). Thus all the living substance is connected. More than this, the contents of one cell are linked up with those of neighbouring cells by fine threads of protoplasm (only made visible by a special technique) which penetrate the walls.

Vacuoles are spaces in the cytoplasm very characteristic of mature plant cells. They do not occur in the same cells when young (cp. Fig. 5 A); in these the dense protoplasm fills the cell cavity. The vacuoles are filled with *cell sap*, a watery fluid which contains various substances in solution. To complete our picture of the structure of a plant cell we must remember that the living contents are in motion inside the cell-wall. This movement may often be observed with the microscope.

THE GREEN PLANT CELL. The cells of the onion scale are colourless, but most plant cells are green. In the higher plants these green cells occur particularly in the leaves.

Exercise. The leaves of mosses or of the Canadian water-weed (Elodea) are very simple in structure. Remove a young leaf from one of these plants, mount it in water, and examine with lens or microscope. In the living cell the cytoplasm and nucleus are often invisible.

Fig. 5 C shows some green cells from the leaf of Elodea. In addition to the structures already enumerated, each contains a number of small round green bodies which appear at first sight to fill the cell, imparting to it a very characteristic colour. They are protoplasmic structures known as *chloroplasts* which are scattered irregularly in the colourless cytoplasm.[1]

[1] Similar small but colourless structures, called plastids, which are forerunners of the chloroplasts, are probably present in nearly all plant

The protoplasm of the chloroplast is sponge-like, and holds a mixture of pigments—green, yellow, and yellow-red—in its meshes. The green pigment predominates; it is called *chlorophyll* and gives the well-known colour to all green plants.

Exercise. Immerse some fresh leaves in warm methylated spirit, and leave until they are colourless. A solution of chlorophyll is thus obtained. Observe that this looks bright green when the light shines through it, but wine-red when light is reflected from its surface.

In most cells the chloroplasts are small spherical or ovoid structures which can grow and divide. Look for stages in their division (marked by a dumb-bell-like appearance) when you examine a moss leaf. Occasionally, these bodies assume a different form, as is shown in the next exercise.

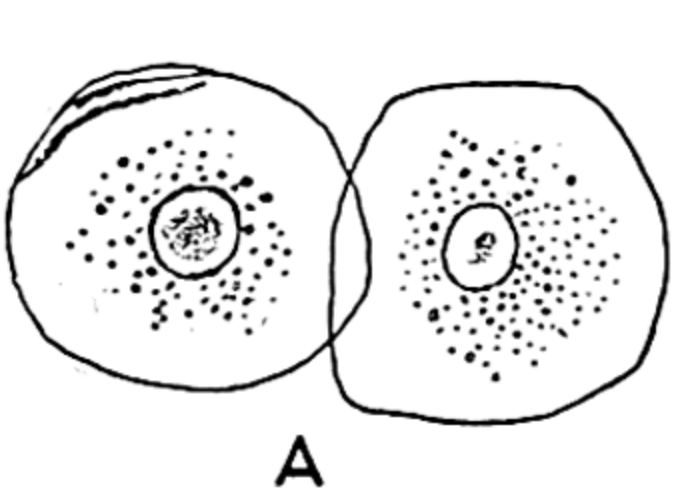
Exercise. You are given some threads of Spirogyra, a green plant of simple structure which is often found floating on top of the water in ponds and shallow streams. Mount one or two of the threads in water and examine them with lens or microscope.

A Spirogyra plant consists of a single row of similar cells which form an unbranched filament. The structure of these cells is shown in Fig. 5 D. The chloroplasts are very striking, each consisting of a spirally twisted green band lying in the cell cytoplasm. The edge of this band is wavy and irregular, and conspicuous little structures called pyrenoids are visible at intervals along its length. In some species of Spirogyra there is one such chloroplast in each cell, in others there may be several. Each cell has a cellulose wall, nucleus, cytoplasm, and vacuoles filled with cell sap, as in the plant cells already described.

THE ANIMAL CELL. Let us compare these plant cells with cells obtained from an animal. Figure 6 shows some simple animal cells which you can easily mount for yourselves.

Exercise. Gently scrape the inside of your cheek with a clean spatula and mount on a slide in a little saliva. Make a similar preparation from the inside of the frog's mouth, mounting the

cells. In green cells these develop into chloroplasts; in others they may become chromoplasts, containing yellow or red pigment. Often they remain colourless.



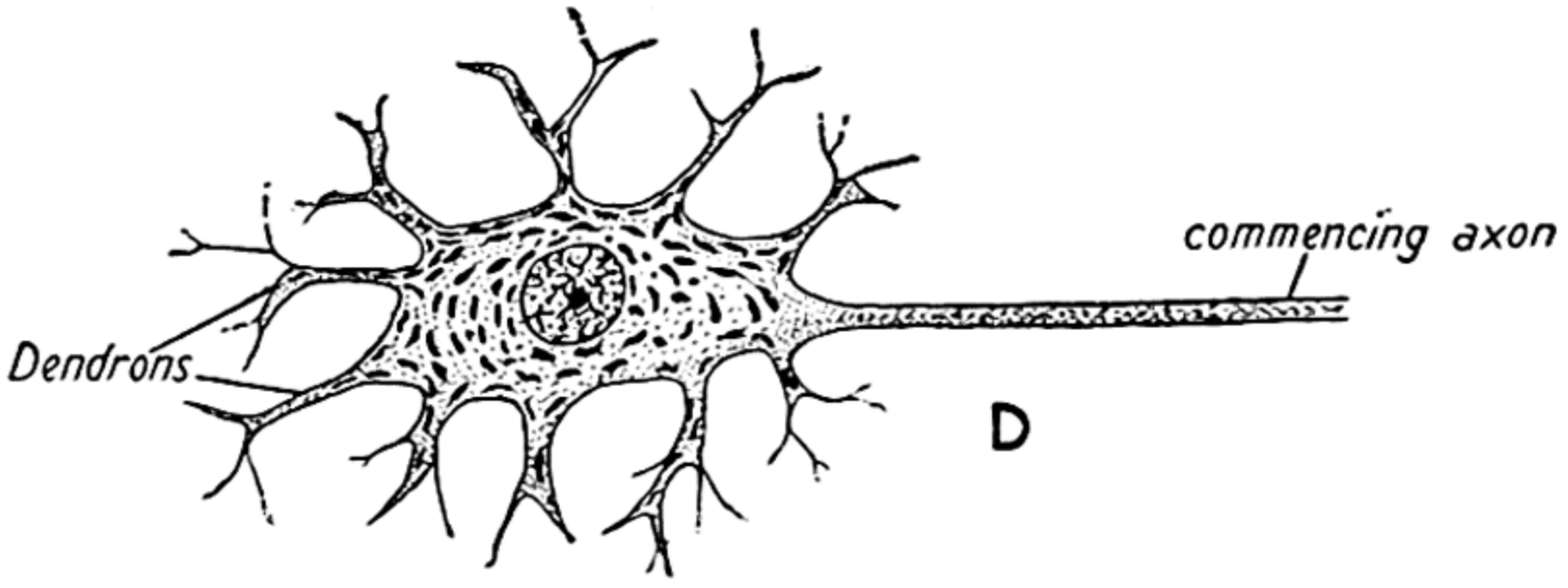
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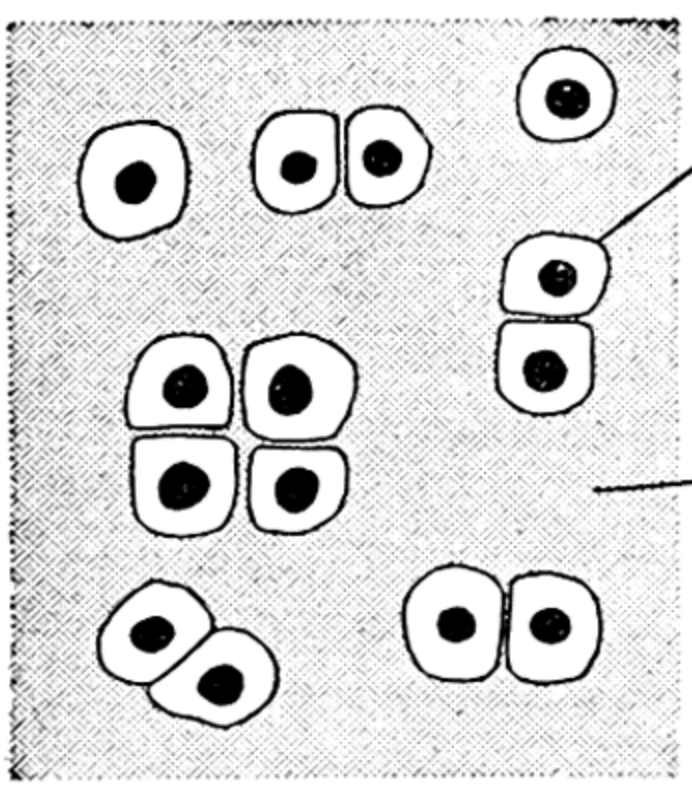
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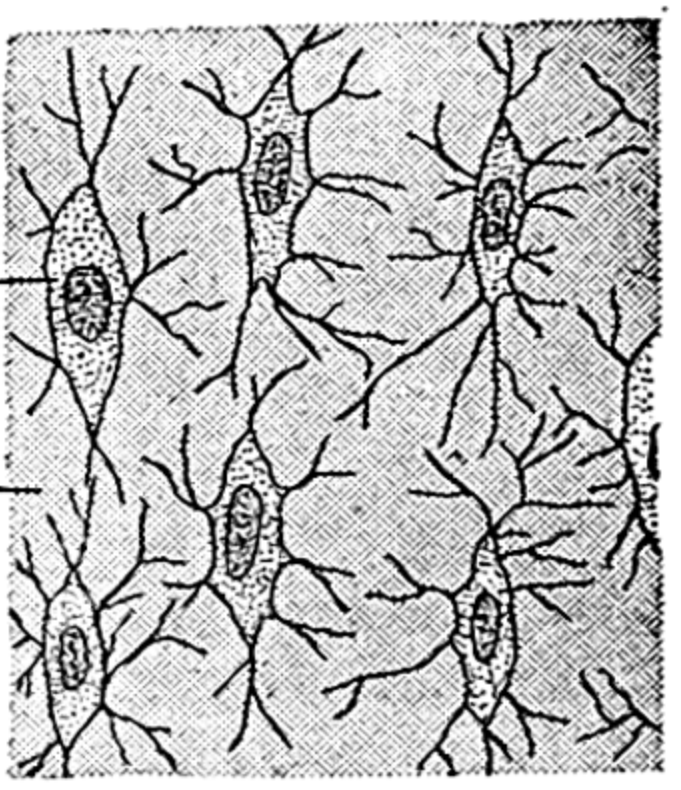
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E



F

FIG. 6. ANIMAL CELLS AND TISSUES. **A.** Two cells from epithelial lining of human cheek. **B.** Two ciliated epithelial cells, and, **C**, a secretory cell, from lining of frog's mouth. **D.** A nerve cell or neuron. **E.** Cartilage. **F.** Bone. In **E** and **F** the cells are embedded in the matrix which they have formed. (All greatly magnified and diagrammatic)

scrapings in a 0·75 per cent. salt solution. Examine these preparations with microscope or microprojector.

The animal cell, like that of the plant, consists of cytoplasm and nucleus, but it is not enclosed in a non-living wall, being bounded by a living membrane. As a jelly when it begins to set may cover itself with a skin which, though in a different 'state' from the more liquid jelly within, is nevertheless a skin of jelly, so in these animal cells the surface consists of a film of more solid but living protoplasm.

This absence of a non-living wall is one of the chief differences between plant and animal cells. Another great difference is the absence from the animal cell of the green colour so characteristic of plants. In animal cells, too, very high magnification reveals a small body outside the nucleus, called the centrosome, which, as we shall see later, plays an important part in cell-division. These centrosomes rarely occur in the ordinary cells of plants, while, on the other hand, the large vacuoles which exist in so many plant cells are not found in those of animals.

Further exercises on cell structure. If you have the use of a microscope or a microprojector you should examine other cells; these instruments will reveal a whole new world. Among objects suitable for study are:

(1) The epidermis stripped from a leaf of iris, daffodil, hyacinth, &c.
(2) Small unicellular green plants such as Pleurococcus. These form the green powder that can often be scraped off the bark of a tree.
(3) Hairs; e.g. root-hairs, hairs of Tradescantia, &c.
(4) Pollen grains.
(5) Cells obtained by teasing apart ripe plant tissues; e.g. tomato pulp, the flesh of an apple, privet berries, &c.
(6) Cells seen in teased-out animal tissues, such as muscle cells.
(7) Cells seen in prepared slides of animal tissues; e.g. cartilage.
(8) Animal blood; e.g. frog's blood, your own blood.
(9) The tiny creatures which abound in stagnant water.

CELLS AND TISSUES. In the higher plants and animals the cells are not all alike but become specialized in structure, forming tissues with definite functions. In many cases the *walls* of plant cells become much altered by the addition of

such substances as lignin ('wood') or suberin ('cork') to the original cellulose wall. Often the living contents of the cell die as these changes occur, leaving only the walls. The cork which Hooke (cp. p. 16) described was a dead tissue of this kind, its cell-walls suberized.

In flowering plants we notice particularly *mechanical tissues*, in which the cell-walls are much thickened and strengthened to give support; *corky tissues*, where structures impervious to gases are required, as on the trunks of trees, covering winter buds, &c.; *conducting tissues*, through which water and food substances can move rapidly about the plant. Vessels are very important elements in such tissues (cp. Fig. 22). They are formed from rows of cells whose transverse walls are all more or less absorbed as the protoplasm dies and the walls thicken and lignify.

In the higher animals the *protoplasm* of the cells often becomes highly differentiated and shows a definite organization, as in muscle cells, where it is striated, and in nerve cells (cp. Fig. 6 D). Furthermore, the tissues of animals do not consist of cells only. The living cells are often separated by a matrix (cp. Fig. 6 E and F), which is not alive, though it has been formed by the cells which lie embedded in it. Bone is a tissue with a rigid matrix which separates the bone cells (bone corpuscles). This matrix, as is well known, lasts much longer than the living body of which it forms a part.

These different kinds of cells form the tissues of the living body of the animal, each specialized to carry out its appropriate functions—*muscular tissue* for movement, *glandular tissue* for secretion, &c. The tissues are grouped together to form organs, e.g. arms, legs, heart, stems, roots, leaves, &c. An organ is a part of the body specialized to perform certain definite functions.

The structure of one of the higher plants or animals may therefore be expressed thus:

Protoplasm → cells → tissues → organs → organism.

PLANT AND ANIMAL CELLS COMPARED. Every cell is a nucleated mass of protoplasm. There are, however, certain constant

differences between plant and animal cells which we may now conveniently summarize.

(*a*) *Contrast in structure.*

Typical plant cell	*Typical animal cell*
1. Has a non-living cellulose wall.	Its limiting layer is of protoplasm and alive.
2. Has a definite shape due to its wall.	Its shape is not so definite.
3. Possesses chloroplasts and chlorophyll.	Is colourless.
4. Has no centrosome.	Has a centrosome.
5. Usually has large vacuoles filled with cell sap.	Vacuoles, if present, are quite small.

In plants or animals whose bodies consist of one or of a few similar cells we see very clearly that these differences in structure are directly related to differences in their mode of life. If, for example, we contrast a pleurococcus or spirogyra, both very simple green plants, with an amoeba or other simple animal, we find the following differences between their living processes:

(*b*) *Comparison of living processes.*

Typical simple plant, e.g. Spirogyra	*Typical simple animal*, e.g. Amoeba
1. Cannot carry out movements of locomotion.	Can move from place to place.
2. Cannot ingest solid food (1 and 2 depend on the presence of a non-living wall).	Can ingest solid food (1 and 2 depend on the fact that the limiting membrane is alive).
3. Can make its own food from simple inorganic substances (3 depends on the presence of green chloroplasts, and can only take place in the light).	Cannot make organic food but must obtain it ready-made from a plant or another animal (since these cells are not green).

These differences, as will appear later, are not only true of simple plants and animals, but are true generally. They are the fundamental differences between the two great subdivisions of the world of living organisms, and we see that these differences in way of life are directly connected with the cell structure.

QUESTIONS ON CHAPTER II

1. Make labelled drawings to illustrate the structure of any flowering plant with which you are familiar.

2. Make labelled sketches of the leaves, stems, buds, flowers, and fruits of any *three* flowering plants.

3. Make sketches of any pet animal you possess, and label all its parts. Describe its organs and methods of locomotion, and say what you give to it for food.

4. Sketch any *three* of the following: an earthworm, a fish, a frog, a reptile (e.g. a snake or a tortoise), a bird, a mammal. Say why they are all classed as animals.

5. Describe the parts of a modern microscope, and give a labelled sketch of the instrument you use.

6. Explain how you would obtain and mount a living green cell for examination under the microscope. Give a sketch of the cell, and describe its structure.

7. Describe, with sketch, any non-green plant cell which you have examined. Say how it was obtained and how mounted for examination.

8. Describe the structure of any animal cell, and point out the chief features in which it differs from a typical plant cell.

9. If you were given any living object to examine, how would you try to determine whether it was a plant or an animal?

10. What do you understand by a cell? Describe as fully as you can the structure of Amoeba, Chlamydomonas, and a mesophyll cell in the leaf. (Ox.L.)

11. What do you understand by the term 'cell'? What are the essential parts of a cell? In what ways do plant and animal cells usually differ from one another? (L.G.S.)

12. If you were asked to classify a number of living organisms (including some microscopic ones) into plants and animals, by what considerations would you be guided? Illustrate your answer where possible, by reference to named examples. (C.L.)

CHAPTER III

AMOEBA PROTEUS

In the surface mud of fresh-water ponds we may sometimes find little specks of colourless protoplasm. Each speck is a tiny animal, its name Amoeba proteus. It is a unicellular creature of very simple structure, whose very existence remained unknown until fairly modern times. It was first described and drawn in 1755 by Roesel of Nuremberg, who examined it with a microscope of his own making. How is life maintained in so minute a creature?

Exercise. Examine under the microscope a stained and mounted preparation of an amoeba. Examine also and sketch a living amoeba; make several sketches to show how it is changing its shape.

STRUCTURE AND MOVEMENTS. The body of an amoeba, like that of every cell, consists of cytoplasm and a nucleus. The *cytoplasm* is of irregular shape, and is separated into:

(1) An inner, granular liquid mass called the endoplasm.
(2) An outer, clearer, more solid layer of ectoplasm.
(3) A tough outer pellicle, forming the limiting layer or surface of the animal. (Cp. Fig. 7, p. 34.)

The *nucleus* is not always visible in the living animal, but is easily seen after the application of a suitable stain.

Other structures present are:

A contractile vacuole. This is a clear space in the endoplasm which alternately fills up with a watery liquid and then contracts, expelling the fluid to the exterior.

Food vacuoles. These are spaces in the protoplasm containing particles of food. Each particle is suspended in a minute drop of water. The food consists of small fragments of organic matter, plant or animal. These vacuoles are not permanent organs; each one lasts until the food it contains has been digested.

MOVEMENT AND THE INGESTION OF FOOD. If we observe a living amoeba for any time we see that its shape is constantly

changing. It keeps thrusting out blunt processes called *pseudopodia*. By these it moves in any direction whatever, crawling or gliding over the surface on which it rests; by these it also obtains its food. It simply thrusts out two pseudopodia, one on each side of any suitable morsel, and engulfs or ingests it, the pseudopodia meeting round the food particle.

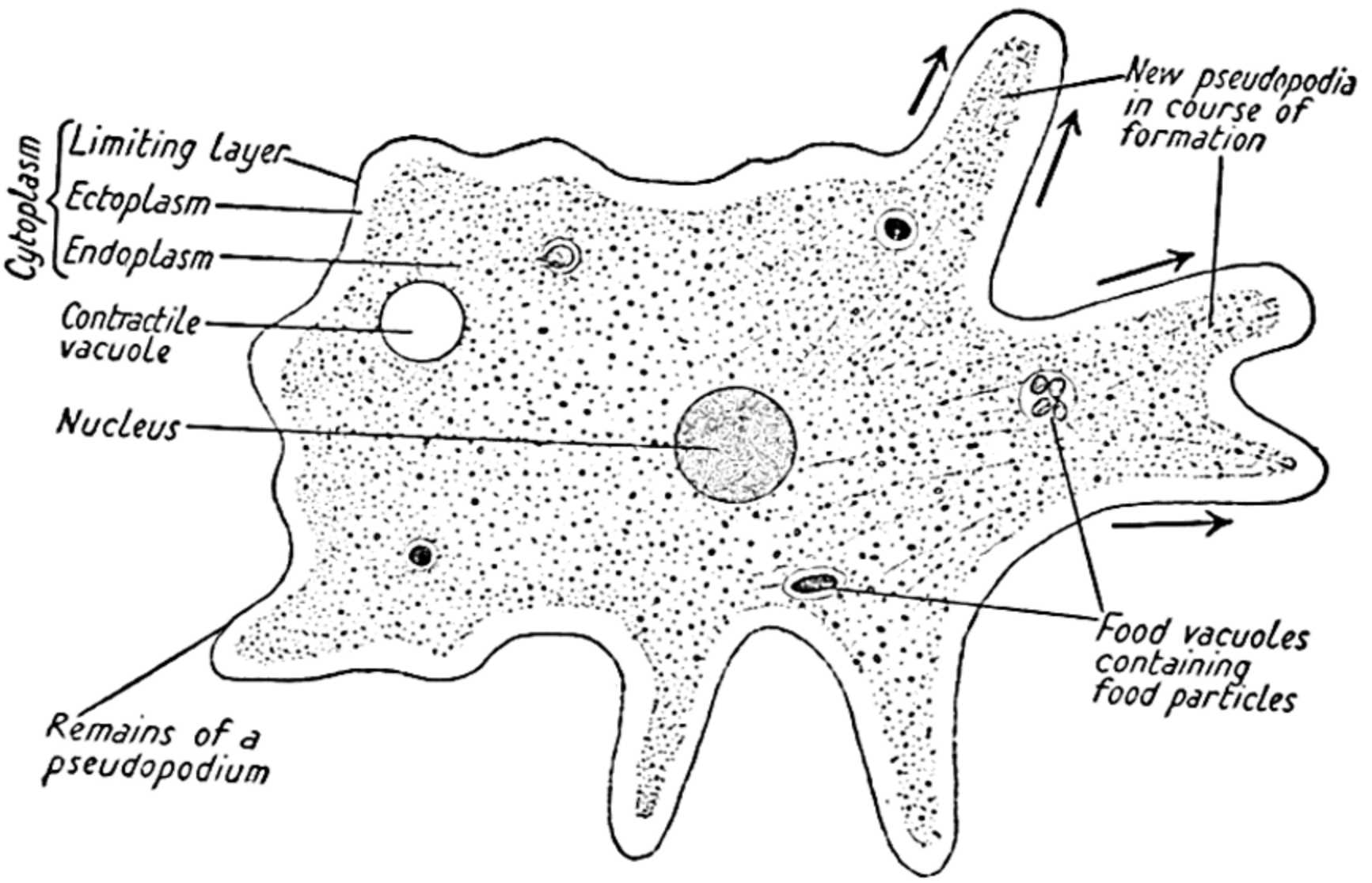


Fig. 7. Amoeba proteus in active movement, which is indicated by arrows. (Highly magnified)

The formation of a pseudopodium begins by a bulging of the surface film or pellicle at one point of the animal's surface. After this the ectoplasm in the neighbourhood becomes more liquid and begins to flow into the bulge, together with the liquid endoplasm and its granules. As the body is extended in one direction it shrinks in another; the protoplasm is obviously liquid.

Some one once timed an amoeba in its progress across a microscope slide, and found that it took one minute to move 0·2 mm., or, in other words, that it was moving at the rate of 12 mm. an hour. Not an overwhelming speed, yet the pace is apparently great enough for this animal's somewhat leisurely existence.

LIFE PROCESSES IN AMOEBA

FEEDING, DIGESTION, AND ASSIMILATION. We have seen that an amoeba ingests little particles of solid food, plant or animal, engulfing at the same time a little water and so forming a food vacuole. The food in these vacuoles gradually disappears and is absorbed into the cytoplasm; in biological language it has been digested and assimilated. It is not easy to study these processes in so small an animal, but we shall examine them later when we study digestion in some of the larger forms (cp. Chapters XII, XIII, XIV). In an amoeba it has been shown that the fluid in the food vacuole, which is at first alkaline, becomes acid and then alkaline again. These facts suggest that chemical changes are occurring there which resemble those that take place in our own digestive organs. There a similar change from an acid to an alkaline reaction occurs as our food is converted into soluble substances with fairly small molecules. This conversion is the essence of digestion. These substances are absorbed and eventually built up into new protoplasm. This is the essence of assimilation. The indigestible residue is rejected. In Amoeba the animal simply flows away from it, discarding it at a temporary anus, while the food vacuole disappears when the digestion of its contained food is completed.

To digest its food and to make the movements necessary for capturing it—indeed for all its living processes—an amoeba requires energy. How is this obtained?

RESPIRATION. This is the name of the universal process by which protoplasm obtains energy. Oxygen from the surrounding medium comes to the protoplasm; in an amoeba it passes through the surface pellicle dissolved in water. By means of this oxygen the fats, sugars, &c., which the protoplasm obtains in its food are rapidly 'burned' there to provide the required energy. This process of oxidation is called respiration, and we shall study it in much greater detail later (cp. Chapter XXI). It leads to the formation of waste matters, e.g carbon dioxide.

EXCRETION is the getting rid of any waste substances, and

also of any substances which, although absorbed into the body, are unwanted by it (cp. Chapter XXVI). In an amoeba most waste substances simply diffuse out through the surface proto-

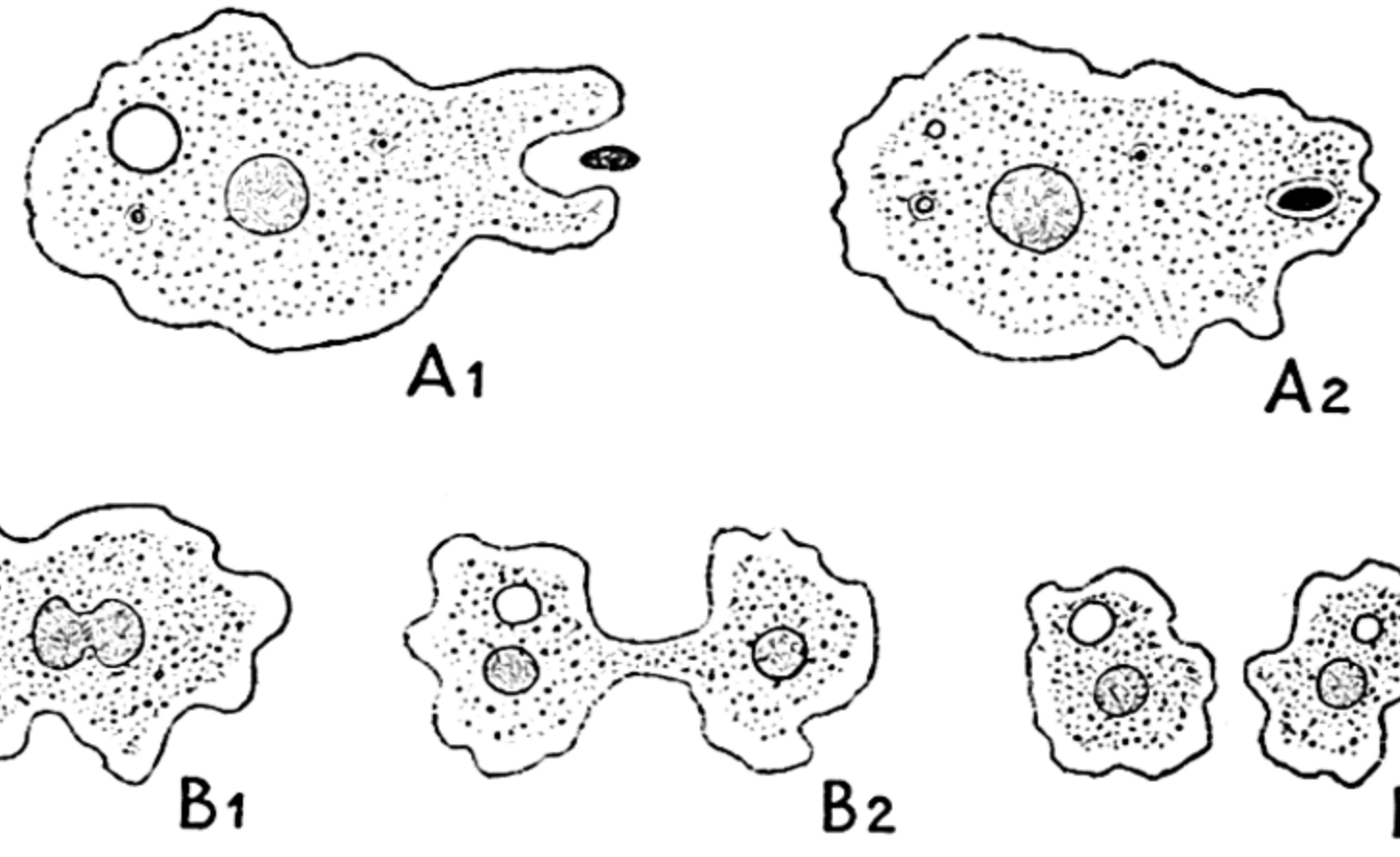


FIG. 8. LIFE PROCESSES IN AMOEBA. **A.** *Ingestion of food.* **A_1.** Two pseudopodia are being thrust out to surround the food particle. **A_2.** The particle has been ingested and a temporary food vacuole formed. **B.** *Reproduction by binary fission.* **B_1.** Nucleus dividing. **B_2.** Nucleus divided. Cytoplasm dividing. **B_3.** Two 'young' animals formed. A second contractile vacuole has developed. **C_1.** *Encystment.* **C_2.** Escaping from the cyst

plasm, but the contractile vacuole is a definite excretory organ getting rid of superfluous water. This water perhaps contains a little nitrogenous waste.

RESPONSE TO STIMULI. The amoeba is sensitive to changes in its environment, as are all living organisms. If it is cold it moves slowly or not at all. Raise the temperature somewhat (about 30° C. seems to suit it best) and it moves more rapidly,

its vacuole contracts more frequently, all its living processes are accelerated. It dies if it is frozen. An amoeba responds to many other stimuli, electrical, chemical, mechanical, &c. This sensitiveness to stimuli is a character which it shares with us and with all living things. It is one of the chief attributes of the living organism.

REPRODUCTION. We have not completed our tale of the life-processes of an amoeba. How does its life begin—and end? Having fed and formed new protoplasm the animal grows, but not indefinitely. When it has reached its full size, reproduction occurs. This takes place very simply by fission, that is, by division of the whole body into two similar halves. An amoeba does not die, unless by accident; its little life is not 'rounded by a sleep'; it just divides into two new and 'young' animals. The nucleus divides first, the process being a complex one (cp. p. 42). Then the protoplasm becomes gradually tucked in between the two daughter nuclei until gradually the parent animal divides into two (cp. Fig. 8 B). The two amoebae thus formed feed, grow, and become mature; then in their turn they reproduce in the same manner.

ADVERSE CONDITIONS. Although merely a speck of unprotected protoplasm, an amoeba is capable of withstanding adversity. If drought, cold, or other dangerous conditions arise, it withdraws its pseudopodia, making its surface as small as possible, and then secretes round itself a protective covering (cp. Fig. 8 C). Safely tucked up in this case or cyst, it remains dormant (encysted) until better conditions prevail.

PROTOZOA. Such is the life of Amoeba proteus. We may regard it as typical of the life of any simple animal. Many of these unicellular forms (Protozoa) exist. They are found everywhere: in sea and fresh water; in soil and air; in and on the bodies of other plants and animals. So numerous are they that their study forms a special branch of biology called protozoology. Unicellular plants are likewise legion. To the study of bacteria alone, many scientists devote their whole working lives.

QUESTIONS ON CHAPTER III

1. Describe the structure of an amoeba, showing how it obtains food and oxygen, and how it gets rid of its waste material.

2. Describe the method of reproduction in Amoeba, showing the part played by the nucleus in this process. How does this reproduction differ from ordinary cell-division?

3. Mention some of the principal differences between living and non-living things.

4. With special reference to Amoeba, give a detailed description of the diagnostic characters of a living organism. (L.G.S.)

5. Give an account of the general structure and physiology of Amoeba. Illustrate with sketches. (C.W.B.)

6. Why is an amoeba regarded as an extremely interesting organism? (C.W.B.)

7. Give a fully illustrated account of the structure of Amoeba, and point out those features which are typical of animal cells. Compare the mode of nutrition of Amoeba with that of any mould you have studied. (L.G.S.)

8. Describe all the features, both of structure and of function, that are common to all living cells. Show by reference to Amoeba and Spirogyra the main differences between plant and animal cells. (L.G.S.)

9. Define the terms—(*a*) cell, (*b*) tissue, (*c*) organ, and (*d*) organism, and give one example of each. Under which heading would you place Amoeba, and why? (Ox.L.)

10. Make a labelled drawing to illustrate those features of a living amoeba which you have seen under the microscope. Describe the movement and method of feeding of the animal. (C.L.)

11. Explain why a rabbit and an oak-tree are (*a*) both described as living organisms, (*b*) placed in separate kingdoms. [Oversea candidates may read 'mammal' for 'rabbit' and 'tree' for 'oak-tree'.] (C.L.)

12. How would you determine whether a body is (*a*) living or non-living, and (*b*) plant or animal? (Ox.L.)

CHAPTER IV

THE GENERAL COMPOSITION OF LIVING MATTER

VITAL ACTIVITY. All living things are, as we have seen, built up of cells, each cell being a nucleated mass of protoplasm. In studying the life of an amoeba we were studying the characteristic properties of living protoplasm. The chief of these are:

1. *Irritability*, or the power of responding to stimuli; it can react to changes in its environment.

2. *Metabolism*, the power of carrying out the complex physical and chemical changes on which life depends. Constructive processes, which lead to growth and the formation of new protoplasm, are called anabolic. The chief among these are food-getting, the ingestion, digestion, and assimilation of that food. Destructive processes such as respiration are called katabolic; by these energy is set free.

3. *Excretion.* Excretory processes serve to eliminate the waste products formed during metabolism.

4. *Reproduction*, the power of making more protoplasm like itself.

These properties all distinguish it from lifeless matter.

FORM. Living creatures are also distinguished by the possession of definite and easily recognizable *forms*. The form even of an amoeba is quite characteristic, in spite of the continual changes which it undergoes. There is some constancy underneath these fluctuations. We generally recognize individual plants and animals by their characteristic forms.

PROTOPLASM. What is this living protoplasm whose behaviour is so different from that of lifeless matter? It contains the elements carbon, hydrogen, oxygen, nitrogen, sulphur, and traces of others. So much can be learned from a simple chemical analysis, but the necessary procedure inevitably kills the protoplasm. The aim of the modern biochemist is to investigate the chemical structure and reactions of the *living* substance, in which we, as biologists, are chiefly interested. This

is something much more than a chemical compound. It is a solution, usually neutral or slightly alkaline in reaction, of a large number of chemical substances, all dissolved in water, and it has a definite structure. It is immensely complex and unstable.

Even the highest magnifications yet obtained with the microscope have not revealed this structure completely; with ordinary magnifications it often appears as a transparent, watery fluid; sometimes, as in Amoeba (cp. Fig. 7), it contains various granules and globules which make it somewhat opaque. It exhibits some of the properties of a jelly. It can, for example, easily pass from the fluid (sol) condition to the more solid (gel) state and back again, as does a solution of gelatin or glue when it melts or sets. These changes in the protoplasm are reversible, just as they are in a jelly. This ability to change from a 'sol' to a 'gel' is characteristic of a whole group of solutions, called *colloidal* (Gk. *kolla*, glue). Gum and glue are solutions of this kind, and serve to illustrate some of their characteristic properties. In them the dissolved particles, though too small to be seen even with a very powerful microscope,[1] are much larger than those of *crystalloids*. In the latter, e.g. salt solutions, the dissolved substances are present in the form of chemical molecules, or of those still smaller particles known as ions, each of which carries a minute electric charge. Perhaps you have already learnt something about these minute units of matter in your chemistry lessons. They are less than one-millionth of a millimetre in diameter.

The degree of subdivision characteristic of *colloids*, where the particles range in size (roughly) from one-millionth to one-ten-thousandth of a millimetre, exposes an enormous surface of the dissolved substance to the molecules of the solvent. Many of the characteristic features of colloids depend on this large interface, the differences between the two types of solution being due to differences in the *size* of the dissolved particles, and not to any chemical differences.

The work of recent years has made it clear that protoplasm

[1] They can be made visible as points of light with an instrument known as the ultra-microscope.

is a colloidal system containing a large number of chemical substances, crystalloids as well as colloids, all dissolved in water, which forms from 60 to 90 per cent. of the whole. The younger, more vigorous, and more active the protoplasm is, the more water it contains. The chief dissolved substances contained in it are:

1. *Proteins.* These are the most complex of all chemical compounds. They have very large molecules, consisting of some thousands of atoms arranged in a definite pattern. They contain the elements carbon, hydrogen, oxygen, nitrogen, sulphur, and sometimes phosphorus, and are the most important constituents of the protoplasm; hence their name—proteins, a word meaning 'of the first importance'. These substances are again described in Chapter V.

2. *Carbohydrates.* These are compounds of the elements carbon, hydrogen, and oxygen, in which the hydrogen and oxygen are in the proportions in which they occur in water (cp. Chapter V).

3. *Fats*, compounds of carbon, hydrogen, and oxygen, in which the ratio of oxygen to hydrogen is less than 1 : 2 (cp. Chapter V).

4. *Various inorganic salts*, which may form about 1 per cent. or more of the weight of the protoplasm. These salts are similar to those dissolved in sea-water.

All these substances form protoplasm; in muscle, for example, their relative proportions are: water 75 per cent., proteins 19 per cent., carbohydrates 0·3 per cent., fats 3 per cent., mineral salts 3 per cent.

FORMATION OF NEW PROTOPLASM. How is this complex substance formed? The ancients thought that life arose from 'Mother Earth', from the sea, from slime; that bees, for example, could be generated from the decaying carcass of an ox. Many such ideas were current in the past; we know now that protoplasm is always formed by pre-existing protoplasm. Life begets life and, so far as our present knowledge goes, it cannot come into existence in any other way. Since protoplasm occurs in nucleated units called cells, the formation of new protoplasm leads inevitably to the formation of new cells.

THE FORMATION OF NEW CELLS BY CELL-DIVISION. New cells are always formed by the division of pre-existing ones, nuclei by division of pre-existing nuclei. Most organisms begin life from a single cell; by constant division, this may eventually produce a multicellular adult body. The nucleus is usually the first part of any cell to divide,[1] this division of the nucleus being soon followed by division of the whole cell. If the organism is unicellular, the two cells simply separate (cp. Fig. 8), and we have two new individuals. In the case of multicellular organisms the new cells remain together and add to the size of the body; hence in these creatures cell-division usually leads to growth of the whole organism.

Exercise. Examine onion cells (cp. p. 25), and carefully notice the nucleus and nucleolus.

Exercise. Examine, with microscope or microprojector, slides specially prepared and stained to show stages in the process of nuclear division.

DIVISION OF THE NUCLEUS. The chief events in the division of the nucleus are illustrated in Fig. 9. The nuclear membrane soon disappears, and a number of solid deeply staining rod-like bodies, the *chromosomes*, become visible within. Something very definite is happening here, for each plant or animal has its characteristic number of chromosomes which reappear at every cell-division. In human beings the number is 48. Each chromosome soon splits longitudinally, so that it is divided into two exactly similar parts. The two halves move apart along certain spindle fibres which have appeared in the cytoplasm, and from each of these groups of half-chromosomes a new nucleus is organized, which becomes enclosed in a new membrane. This division of the nucleus is soon followed by that of the whole cell. If an animal cell is dividing, the protoplasm

[1] In animal cells division of the centrosome precedes and initiates the division of the nucleus.

FIG. 9 DESCRIPTION. **A.** Centrosome has divided. **B.** Nuclear net has become subdivided into separate chromosomes. **C.** Each chromosome has split lengthwise into two. **D.** Separation of the chromosomes. **E.** Nuclei re-forming; cell dividing. **F.** Two cells formed. (Diagrammatic)

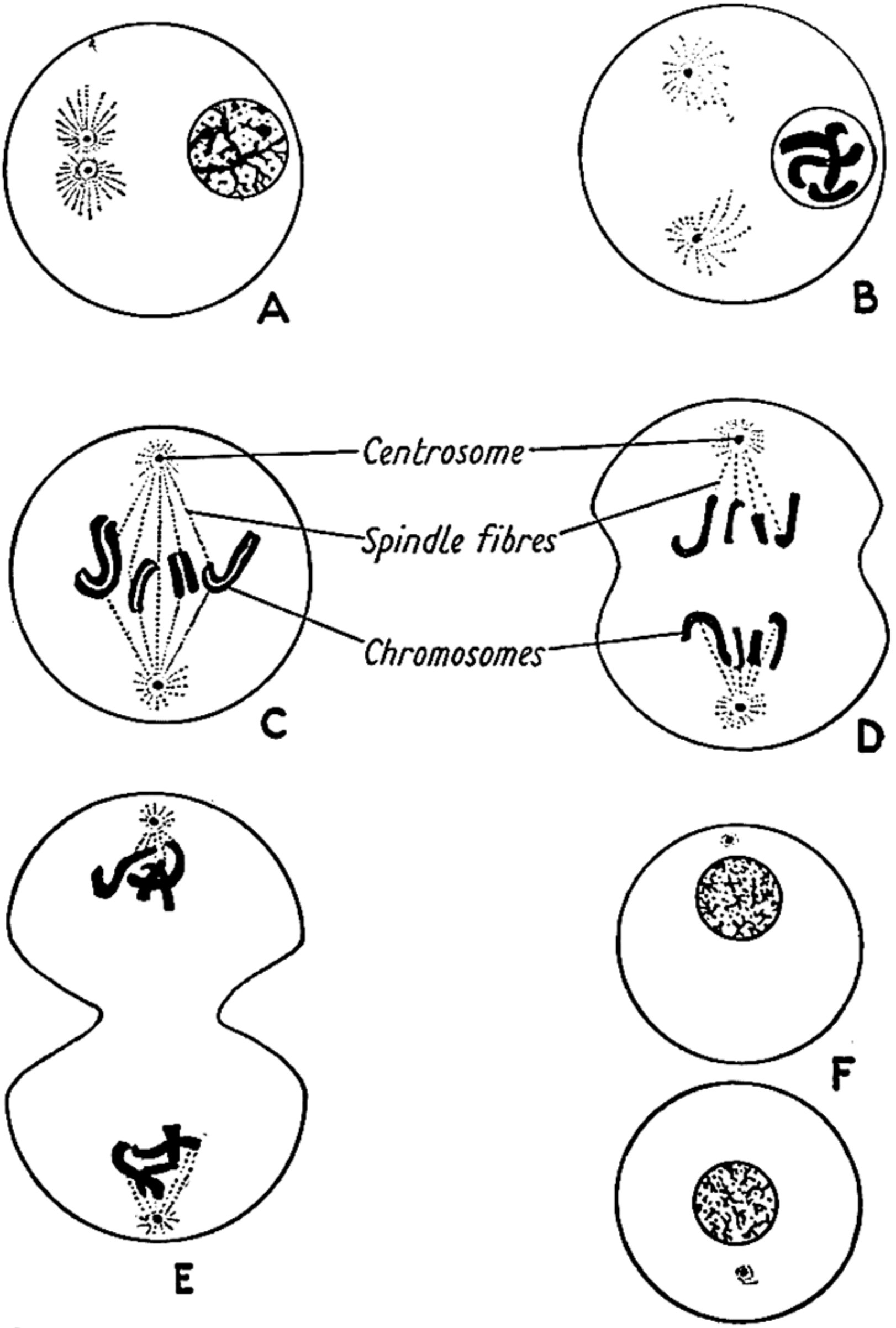


FIG. 9. NUCLEAR DIVISION IN AN ANIMAL CELL WITH FOUR CHROMOSOMES. See p. 42 at foot

simply becomes tucked in between the two newly formed nuclei. If it is a plant cell a new section of cellulose wall is formed, separating the two nuclei.

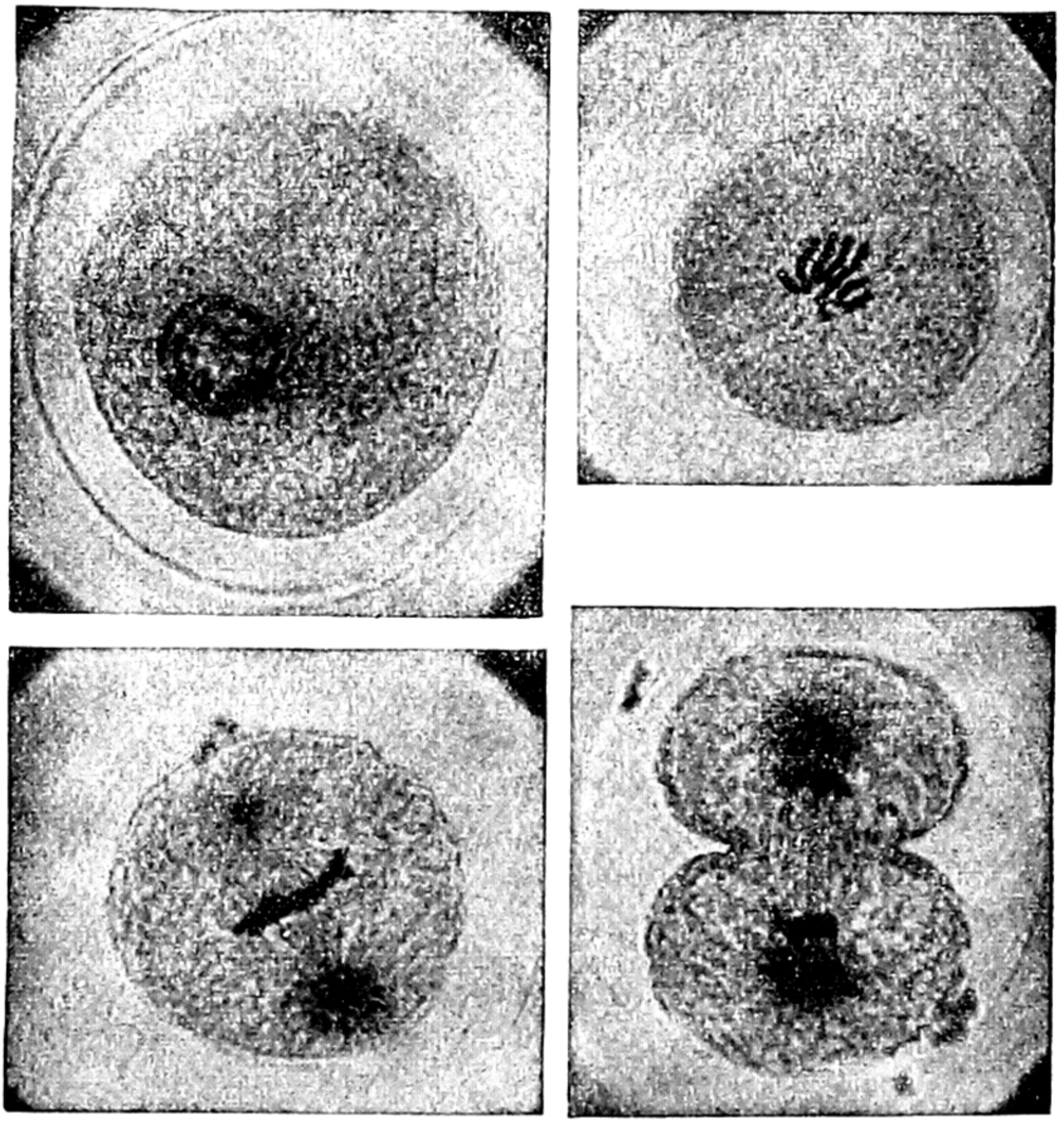


FIG. 10. Photographs (taken through the microscope) of four stages in the division of a nucleus.

CELL-DIVISION, A SUMMARY. We see that the process of cell-division is a very intricate one. It is similar in nearly all cells, and proceeds step by step in an orderly manner, the behaviour of the chromosomes reminding one of a company performing some elaborate figure in a formal dance. The process usually

takes less than half an hour to complete, and perhaps there is nothing in the whole realm of biology which is better calculated to make us realize the hidden and mysterious activities of which protoplasm is capable. The protoplasm is highly organized, and we must not think of a cell as like a single room, in which certain chemical processes are occurring in a higgledy-piggledy manner, as they occur during an ordinary chemical reaction in a beaker. The cell should rather be compared to a well-organized chemical factory, with different processes occurring in different parts of it, and where substances are being elaborated as fast as they are required.

The microscope is a most useful instrument, but even its highest powers do not enlarge enough for us to see the *structure* of the protoplasm, and so much of this organization is still hidden from us. It is by its *vital activities* that we can best recognize protoplasm. We do not know what life is; we can only describe these activities. Every creature feeds, grows, and develops; responds to stimuli; excretes, and propagates its own kind. Every creature also has a characteristic form. These are the unique properties of protoplasm by which its life is made manifest.

THE EXPERIMENTAL STUDY OF LIVING MATERIAL. It is possible for even the least chemically minded of us to learn something for ourselves about the composition of living matter, for it contains water and various organic substances which are decomposed by burning, leaving an incombustible residue, the ash.

Experiment 1. To determine the percentages of water, combustible material, and ash in any given substance we proceed as follows. Weigh the given substance, e.g. fresh leaves, dry seeds, white of egg, a lump of yeast, lean meat, &c., and dry it in a water-jacketed oven until it reaches a constant weight. This weight is the *dry weight* of the given material.

The dry substance is now placed in a crucible and strongly heated until everything combustible has been decomposed into simpler substances, such as carbon dioxide, water, ammonia, &c., which escape into the air. Finally only ash is left. By weighing this we find the weight of combustible matter in our sample, and now a simple calculation enables us to determine the percentages of water, combustible material, and ash contained therein.

COMPOSITION OF CERTAIN LIVING ORGANISMS. 100 parts of living material contain:

	Water	*Combustible material*	*Ash*
Lettuce leaves . .	94·33	4·64	1·03
Potatoes . . .	78·3	20·9	0·8
Jelly-fish . . .	95·39	1·61	3·0
Carcass of Ox . .	45·6	49·8	4·6
Eggs . . .	73·7	25·5	0·8

COMPOSITION OF THE ASH. Analysis of the ash proves that at least six elements enter into its composition: sulphur (S), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and iron (Fe). Many others are usually present, in particular sodium (Na), silicon (Si), chlorine (Cl), and iodine (I), sodium being, in animals, more abundant than magnesium.

The ten elements carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, potassium, calcium, magnesium, and iron, found in all living substance, are often called the essential elements, for experiments (cp. p. 74) have shown that they are all absolutely necessary for healthy growth. It seems likely that many others are equally essential, though often the merest trace is all that is necessary.

QUESTIONS ON CHAPTER IV

1. What do you understand by the word 'protoplasm'? Describe the appearance and distribution of the protoplasm in any cell which you have examined.

2. Describe any experiments which you have performed or seen which illustrate some differences between crystalloidal and colloidal solutions.

3. Enumerate and comment on the characters which distinguish living organisms from all non-living material. (L.G.S.)

4. Say what you know of the chemical composition of protoplasm. Why is this an insufficient account of this substance?

5. Give a short illustrated account of the process of nuclear division.

6. Write short notes on: protoplasm, cytoplasm, chloroplasts, nucleoplasm, nucleus, chromosomes.

PART II
FOOD AND ITS MANUFACTURE

CHAPTER V
FOOD

EVERY living organism must have food; life cannot be sustained for long without it. What is this food on which all creatures depend? It is obvious that the source of supply is not always the same. An amoeba (cp. p. 33) lives on a mixed diet of minute plants and animals. Many animals thrive on very monotonous food; stick insects, for example, can live entirely on privet leaves, silk-worms on mulberry leaves, the caterpillars of the cabbage-white butterfly on cabbage leaves; the clothes-moth larva devours cloth and fur; fleas and female mosquitoes suck blood, while many scavengers enjoy a most unsavoury diet; dung-beetles live happily on manure; germs abound and live on every type of filth.

Passing to the highest group of animals, the mammals, we find that some are purely vegetarian (*herbivorous*), as are the sheep and cow, rabbit and hare; others are purely flesh-eating (*carnivorous*), as, for example, the cat, dog, lion, and tiger; many require a mixed diet.

Men can exist on the most varied foods. Europeans usually eat both meat and vegetables; Greenland Eskimoes, who have a great capacity for physical endurance, are purely carnivorous, living on seal-meat, and the flesh of reindeer, walruses, and whales; the Hindoos, in accordance with their religion, are strict vegetarians, except for the taking of a little milk. The Bahuma tribe who live in the Ankole district of central Africa subsist almost entirely on milk, though certain members eat meat very occasionally. No vegetables, fruit, bread, &c., are ever taken.

'It may interest those who doubt whether a purely milk diet can keep people healthy and strong to know that some of these cowmen

were tested in the Carrier Corps during the war and proved themselves as fit for rough and trying work and as able to carry heavy loads as the members of the meat-eating tribes. In the King's African Rifles, too, many of the young men gained excellent reports of their capacity for endurance.' (Roscoe, *The Soul of Central Africa.*)

The study of feeding habits is extremely interesting, and the student should pursue it further. Whatever may be the source of food, we find that it is used because it supplies some or all of the following substances:

1. Carbohydrates.
2. Fats.
3. Proteins.
4. Vitamins.
5. Mineral salts.
6. Water.

Most of these substances, as we have seen (cp. p. 41), are constituents of protoplasm, and hence they are necessary for its formation.

THE AVERAGE PERCENTAGE COMPOSITION OF SOME COMMON FOODSTUFFS

Food as purchased (before cooking)	*Protein*	*Fats*	*Carbo-hydrates*	*Water*	*Ash*	*Refuse (bone, &c.)*
Sirloin of beef . .	17·1	11·1	..	58·2	0·9	13·0
Leg of mutton . .	15·1	14·7	..	51·2	0·8	18·3
Bacon (smoked) .	9·5	59·4	..	10·4	4·5	8·7
Chicken . . .	12·8	1·4	..	43·7	0·7	41·6
Mackerel . .	10·2	4·2	..	40·4	0·7	44·7
Eggs . . .	13·9	9·3	0·3	65·5	0·9	11·2
Milk . . .	3·3	4·0	5·0	87·0	0·7	..
Cheese (Dutch) .	37·1	17·7	..	35·2	10·0	..
Butter . . .	1·0	85·0	..	11·0	3·0	..
Oatmeal . . .	16·1	7·2	67·5	7·3	1·9	..
Wheatflour . .	10·9	1·1	75·6	11·9	0·5	..
White bread . .	9·1	1·6	53·3	35·0	1·0	..
Honey . . .	0·4	..	81·2	18·2	0·2	..
Tomatoes . .	0·9	0·4	3·9	94·3	0·5	..
Bananas (without skin)	1·3	..	10·9	75·3	0·5	..
Oranges (without skin)	0·8	0·2	11·6	86·9	0·5	..
Apples (without skin)	0·4	0·5	14·2	84·6	0·3	..
Dried peas . .	23·0	2·0	57·0	15·0	3·0	..
Brazil nuts (shelled) .	17·0	66·8	7·0	5·3	3·9	..

THE FOOD REQUIREMENTS OF A HUMAN BEING. It has been found that, in general, the food of an adult man who is not doing hard physical work must contain about 100 grammes of protein, 500 gm. of carbohydrate, and 100 gm. of fat per day. It would take about 1 lb. of fresh meat or fish to supply this quantity of protein, about 1½ lb. of flour or rice to supply the carbohydrate, and about ¼ lb. of butter to give the required fat. But we do not get our proteins only from meat, or our carbohydrates only from flour; we eat a mixed diet and obtain each of these substances from more than one source (see adjoining table).

THE CHEMICAL EXAMINATION OF CERTAIN FOODS. Although the chemistry of the foodstuffs is difficult, we cannot pursue the study of biology very far without knowing something about these materials on which life depends.

CARBOHYDRATES, as we have learned already (cp. p. 41), are compounds of carbon, hydrogen, and oxygen. Simple experiments soon demonstrate the truth of this statement.

Experiment 2. To show that starch contains these elements, gently heat a little in a dry test-tube and allow it to cool. The sides of the tube become covered with small drops of water. (Test with cobalt chloride paper or anhydrous copper sulphate.) Hence starch contains the elements hydrogen and oxygen.

Reheat the test-tube and its contents. More fumes are given off. These contain carbon dioxide. (Test with lime-water on a glass rod.)

Other fumes escape which are smoky, smelly, and inflammable. (Try to light them at the mouth of the tube.) They are chiefly compounds of carbon and hydrogen.

Finally a blackish substance is left in the test-tube, and continued heating does not alter this further. But if the experiment is repeated, using a crucible, which gives better contact with air, the black residue burns right away. It is carbon.

By this experiment we have shown that carbon, hydrogen, and oxygen are present in starch. More chemical knowledge and more accurate experiments would enable us to show that these are the only elements present, and that they occur in the proportions expressed by the formula $C_6H_{10}O_5$. Other commonly occurring carbohydrates are the sugars (there are

many kinds; cp. p. 54), cellulose, glycogen or animal starch, and inulin. They are all similar in chemical composition; they are all decomposed by heat. (Test this statement.)

OILS AND FATS. These, like carbohydrates, are compounds of the elements carbon, hydrogen, and oxygen, but they contain less oxygen. We know how easily they 'burn', i.e. unite with oxygen.

Experiment 3. To show that oils contain carbon, heat some olive-oil in a crucible and hold a lid in the fumes. It becomes covered with a deposit of soot, and soot is a form of carbon.

PROTEINS are extremely complex substances. In addition to the elements carbon, hydrogen, and oxgyen, they contain nitrogen, sulphur, and usually phosphorus. There are an enormous number of different proteins; their exact chemical formulae are only now being worked out. The following average figures give a rough idea of their composition: carbon 50–55 per cent., hydrogen 6·7–7·3 per cent., oxygen 19–24 per cent., nitrogen 15–18 per cent., sulphur 0·3–2·4 per cent., phosphorus 0·4–0·85 per cent. Protein molecules are exceptionally large, consisting of hundreds, or perhaps thousands, of atoms. Casein, for example, the chief protein of milk, probably has a molecular weight of about 188,000; i.e. its molecule is some ten thousand times as heavy as a molecule of water and four thousand times as heavy as a carbon dioxide molecule. It is obvious that the study of proteins will be one of the most advanced and difficult branches of chemistry; nevertheless, we may learn a little about their composition by some simple experiments. Egg-white is well suited to this purpose, as it consists very largely of proteins dissolved in water.

Experiment 4. Heat a little egg-white in a test-tube, and notice carefully the following facts:

(*a*) The substance becomes opaque.

(*b*) A colourless liquid is given off which is deposited on the sides of the test-tube. Test this liquid; it is water.

(*c*) Decomposition continues and fumes escape which:

(i) Have an acrid smell.

(ii) Turn red litmus blue.

(iii) Cause a glass rod, dipped in strong nitric acid and held over the mouth of the test-tube, to 'smoke'.

These three results indicate that the fumes contain ammonia, a gaseous compound of nitrogen and hydrogen (NH_3), which is always formed when a protein is decomposed.

(*d*) With continued heating dense cloudy inflammable fumes escape, similar in appearance to those given off by carbohydrates. They contain much of the carbon and hydrogen of the protein.

(*e*) Finally a black mass of carbon is left in the test-tube. The protein has been completely decomposed.

By such experiments we can illustrate the fact that proteins contain the elements carbon, hydrogen, oxygen, and nitrogen.

MINERAL SALTS. Certain mineral salts are also essential to living protoplasm, which must obtain at least ten elements from its food materials (cp. p. 74). Most human races add common salt (sodium chloride) to their food. In certain parts of Africa and India, where this substance is rare, the natives suffer from 'salt hunger', and will eat it by the handful when they can obtain it, while many wild animals go long distances in search of it. Definite human diseases have been traced to a deficiency in mineral salts; for example, some forms of rickets are due to lack of calcium or phosphorus, both these elements being required to build bone; lack of iodine causes one form of goitre; certain types of anaemia are caused by lack of iron. Hence, although these salts do not add appreciably to body-weight, they are absolutely essential foods.

VITAMINS. The last class of food substances which we have to consider are the vitamins. Until quite recently it was believed that a sufficiency of the food materials already described would maintain any individual in perfect health. The early navigators soon discovered, however, that they did not remain healthy if they lived entirely on preserved food; they developed scurvy, &c. They found that such diseases were prevented by the very smallest quantities of fresh food. Cartier, for example, during his second voyage to Newfoundland in 1535, gave a decoction of fresh pine-needles to his crew of 103 men, only three of whom were free of scurvy; the treatment proved successful. Captain Cook (1728–79) on his voyages served out lemons to his crews to prevent this disease. We now know that every diet must contain small quantities

of certain organic substances, the existence of which only began to be suspected early in this century. The name *vitamines* (later spelt vitamins) was given to these substances by Funk about 1912. Since that date our knowledge of them has increased very rapidly. At least eight different vitamins are now known, all of which are essential for health; indeed, life itself cannot be maintained long without them. Hence they are vitally important constituents of our food. Among human diseases which can be caused by a lack of them are rickets, scurvy, and beri-beri, while quite recently we have learned that decayed teeth are often due to a slight lack of vitamin D.

Since many of these substances are destroyed by the processes of cooking, tinning, and preserving, they are best obtained from fresh food. In an ordinary diet, containing fresh milk, butter, and fresh fruit, there is abundance of these vitamins. Fresh milk has traces of most of them, and if only 3 c.c. of milk are added daily to a diet which is very deficient in vitamins, this is enough to keep one rat in good health. We see that in ordinary life we need not worry too much about the supply of these substances. It is on exploring expeditions, on board ship, in time of war, indeed wherever we have to depend on preserved food or on some very monotonous diet, that we must be on our guard against their lack. One place where we have to consider the supply of vitamins very carefully is in the feeding of young babies; their mothers' milk is very liable to be deficient in these substances, and even greater care must be exercised if they are fed on pasteurized or preserved milk. Orange-juice and cod-liver oil are given to make good any deficiencies.

The eight vitamins so far identified are known as A, B_1, B_2, B_3, B_4, C, D, and E. These names were given when their chemical composition was quite unknown. Since then the chemical formulae of at least four of them have been discovered, three have been synthesized, i.e. manufactured in the laboratory, and we can test for the presence of several of them by chemical means. The following table shows the chief foods from which we obtain the six better-known vitamins.

VITAMIN-CONTAINING FOODS

A	B_1	B_2	*C*	*D*	*E*
egg-yolk	yeast	yeast	orange	cod-liver oil	wheat grain
cod-liver oil	cereals	milk	lemon	cream	olive-oil
carrots	milk	eggs	fresh vegetables	milk	seeds
tomatoes	egg-yolk	marmite	fresh milk	most greens	green leaves
green leaves	meat		uncooked meat	egg-yolk	
cream	oatmeal				
yellow turnips	marmite				
sweet potatoes					
lettuce					
butter					

TESTS FOR VARIOUS FOODS. It is useful to be able to ascertain what substances are present in any given food. Methods of testing for the presence of the commoner food substances are given in the table on p. 54.

TESTS FOR VITAMINS. Until recently no chemical tests for vitamins (such as those given on p. 54 for starch, sugar, &c.) were known, and the presence or absence of these substances could only be tested for biologically. The method of carrying out such tests is extremely interesting, and we give a short account of it.

Rats, guinea-pigs, and similar creatures are given a diet consisting of purified foods of which all the constituents are known. The diet must not contain the vitamin which is being tested for. The animals are fed on this diet until they develop definite symptoms due to lack of the vitamin.

They are then divided into two groups, the experimental group and the control. The substance which is being tested is added in varying amounts to the food of the experimental group. The control group continues to be fed on the original 'deficiency' diet. If the food undergoing test contains the vitamin looked for, the symptoms of disease will disappear in the experimental animals while the control group continue to suffer.

Notice here the importance of a proper 'control'. It is

necessary in a large number of biological experiments. In the one cited we could not be absolutely certain, without such a control, that the recovery of the animals was not due to some other factor.

TESTS FOR VARIOUS FOODS

Food materials	*Test*	*Result*
Starch	Add iodine solution	Blue colour
Reducing sugars	Add Fehling's solution and heat to boiling-point	Brick-red precipitate
Cane sugar (A non-reducing sugar)	Boil in acidulated water. This converts it to a reducing sugar.* Add Fehling's solution (making sure that the acid is neutralized).	Brick-red precipitate
Oils and fats	1. (*a*) Squeeze the substance between folds of filter paper	A translucent stain on the paper
	(*b*) Wash the stain in ether or benzol	The stain disappears
	2. Apply Sudan III	Salmon-red colour
Proteins	1. Millon's test. Add Millon's reagent and heat	Brick-red precipitate on boiling
	2. Xanthoproteic test:	
	(*a*) Add strong nitric acid and warm gently	A yellow colour
	(*b*) Follow by strong ammonia	The yellow colour deepens to orange
	3. Biuret test. Add caustic potash solution, and follow by a copper sulphate solution, added drop by drop	Violet coloration

* Sugars fall into two groups, reducing and non-reducing. Glucose, found in many plants, is a member of the first group, while cane sugar belongs to the second. The composition of cane sugar is expressed by the formula $C_{12}H_{22}O_{11}$; for glucose the formula is $C_6H_{12}O_6$; the one is a double (disaccharide) sugar, the other a monosaccharide (cp. p. 142). When cane sugar is boiled with dilute acid it is converted into two monosaccharide sugars, glucose and fructose, which give the ordinary Fehling's test:

$$C_{12}H_{22}O_{11} + H_2O = C_6H_{12}O_6 + C_6H_{12}O_6$$
$$\text{cane sugar} + \text{water} = \text{glucose} + \text{fructose}$$

SUGGESTIONS FOR FURTHER EXPERIMENTAL WORK. Using the tests given above the student is now in a position to examine

suitable material and to ascertain what food it contains. Seeds (e.g. broad beans, peas, monkey nuts, Brazil nuts, walnuts, &c.), fruits (e.g. apples, grapes, gooseberries, &c.), storage organs (e.g. carrots, beetroots, potatoes, parsnips, onions) are suitable objects to examine. Solid substances, specially plant materials with their resistant walls, should be shredded, crushed with a pestle and mortar, or otherwise finely subdivided before the various tests are applied.

Bread, flour, and milk should also be examined, and the results obtained compared with those given in the table on p. 48.

MILK A PERFECT FOOD.

Experiment 5. Examine a drop of milk under the microscope; we find that it contains large numbers of minute round bodies, the fat-droplets. When the milk stands these rise to the top as the cream. Leave some milk until it has turned sour (this souring is due to the action of bacteria which live on milk); a clear whey separates from the solid curds. Test the curds for protein; they contain the protein and the fat of milk. Test the whey with Fehling's solution; it contains sugar.

We learn that *milk contains proteins, fats, carbohydrates, and water*; appropriate experiments show that it also contains *vitamins* and *mineral salts*. Hence it contains everything essential to life, and is often called a perfect food. Since young babies are fed entirely on milk, and all children need large amounts of it, it is very important that this food as sold to the public should be clean and uncontaminated, free from disease-producing germs, particularly the germs which cause tuberculosis. Much is being done by farmers, dairy men, public authorities, and the big milk-distributing firms to ensure a healthy supply, especially in the large towns.

Each animal's milk is the one best suited to its own young. Very small babies, for example, cannot tolerate cow's milk, although its composition is so like that of their natural food; it has, by the addition of sugar, &c., to be made more like human milk before they can digest it. Later the infant's digestive powers increase, and before it is a year old it is taking bread, butter, &c., being able to digest most simple foods.

The important differences in composition between the two milks most used in feeding human babies are shown in the following table:

PERCENTAGE COMPOSITION OF MILK

	Fats	*Milk sugar (lactose)*	*Protein*	*Mineral salts (ash)*
Human milk	2–4	6·0–7·5	0·7–1·5	0·15–0·30
Cow's milk	2–4	3·5–5·0	2·5–4·0	0·66–0·77

QUESTIONS ON CHAPTER V

1. Name the chief classes of food substances, and say how you would test any given material to ascertain which of these foods it contains.

2. What are proteins? What do you know of (*a*) their chemical composition, (*b*) the tests by which you would recognize them?

3. Give a list of the substances you ate either for breakfast or dinner, and explain as far as possible what food materials you obtained from them.

4. Name three food materials rich in protein, three rich in carbohydrates, three rich in fats, and three rich in vitamins.

5. What is meant by a 'proper meal'? What substances must it contain? What do you think are the chief advantages of a mixed diet?

6. Write a short essay on milk and the importance of a clean milk supply.

7. What are the principal forms in which food is stored by plants and animals? Describe tests which may be used for identifying these substances. (L.G.S.)

CHAPTER VI

THE SOURCE OF THE WORLD'S FOOD SUPPLY

THE MANUFACTURE OF CARBOHYDRATES

Tell me about that harvest field.
Oh! Fifty acres of living bread.
HAROLD MUNRO.

SOURCES OF FOOD. The whole living creation cries out for food, famine being one of the most terrible scourges with which living creatures have to contend. Where does the desired food come from? If you look at the list of food substances given on p. 48 you will see that they are all either of plant or animal origin. Your own food tells the same story; eggs and bacon, greens and potatoes, &c.—go through the list; all these substances come from animals or from plants.

Food materials are not manufactured in human factories. You read of flour mills, of sugar refineries, of beet-sugar factories, of bakeries, of the jam and fruit-bottling industries, &c. All these are closely connected with food-getting; but a little reflection shows you that they are extracting, refining, preserving, and generally preparing food substances which are already in existence. What is the ultimate source of the world's food? Where does it all come from? The following simple experiments will disclose the answer to this question.

Experiment 6. Take Spirogyra plants (cp. p. 27) which have been in the light and mount them in iodine solution. The microscope reveals that the cells contain little *granules of solid starch* (now coloured blue by the iodine) *grouped round the pyrenoids* (cp. Fig. 5). There is no starch in the water in which Spirogyra lives. Where has it come from?

Experiment 7. Pick some green leaves from any plant which has been exposed to the sun. Place them in boiling water and then in warm methylated spirit. When the green pigments have been dissolved out by the spirit, immerse the leaves in a solution of iodine. They become blackish in colour because their *cells contain innumerable starch grains.*

Experiment 8. If thin sections are cut from leaves such as those used in the previous experiment, treated with iodine, and examined under the microscope, we can actually see the starch grains in the cells.

The leaf blade is little more than a mass of loosely arranged green cells grouped round the leaf veins. It is in these green cells, called the mesophyll cells (cp. Fig. 25), that the starch grains occur.

Experiment 9. For this use leaves that have been exposed to the light. Cut them into small pieces and place them in a test-tube. Add Fehling's solution, heat, and look for a brick-red precipitate. The result of such tests is usually positive. *Green leaves contain sugar.*

FOOD SUBSTANCES IN LEAVES. We learn that *green* cells which have been *exposed to sunlight* contain *starch* and *sugar*. Some contain sugar only (e.g. onion leaves); some contain much sugar and little starch (e.g. violet and pansy leaves); others, and this is the more usual condition, contain much starch and less sugar. All contain carbohydrate food.

Experiment 10. If now, repeating experiments 7 and 8, we examine green cells which have been kept about forty-eight hours *in the dark*, we find that they *no longer contain starch.*

Having discovered that starch disappears in the dark, we can begin the next experiment with leaves devoid of starch.

Experiment 11. Remove some leaves from a plant which has been kept in the dark, testing one or two to make certain that they contain no starch. Place the remaining leaves with their stalks dipping into distilled water, and expose them for some hours to *bright sunlight.* Then kill, decolorize, and test with iodine as before.

We find that these leaves *now contain starch.*

Experiment 12. Repeat the above procedure with a Spirogyra plant which has been in the dark. Cut the filament into two, leave one half in water in the dark, expose the other half to sunlight. After some hours of such exposure mount both portions of the filament in dilute iodine solution. The one half (from darkness) contains *no starch*, the other half (from the light) contains *obvious starch grains*, clustered about the pyrenoids.

THE WORK OF THE GREEN CELL. Let us now carefully consider

the conditions under which starch appeared in experiments 11 and 12. There is no starch or any other carbohydrate in distilled water, nor do these occur in air. We are therefore driven to the conclusion that the *carbohydrates are made by the green cells themselves*. Our experiments have revealed one of the most fundamental facts of biology. The green plant is a factory making the world's food; not only the food required by the plants themselves, but all food whatsoever. All animals obtain their food, directly or indirectly, from plants. We begin to understand why over 75 per cent. of the world's human population is engaged in agriculture. The farmers and their labourers are tending the factories which make our food.

The whole process of food-making begins with the manufacture of starch and sugar by green plant cells, and the extent of this great activity is best revealed by a few figures. It was estimated that, in one harvest, the German cereal crop alone contained 9,000,000,000 kilograms of carbohydrate food. One acre of wheat may yield about 2,000 lb. of grain and 4,000 lb. of straw. This means that, on this one small field, about 3 tons of plant material have been formed. Multiply this by all the fields all over the world and you gain some slight idea of the green plant's productivity. An average leaf produces in one season enough sugar to cover itself with a solid crystalline layer 1 mm. thick—i.e. with a layer of carbohydrate forty times thicker than the green tissues by which it was made.

THE RAW MATERIALS USED IN THE MANUFACTURE OF SUGAR.

Thus the green cell is a factory, making food. Like any other factory it requires both raw materials and a supply of energy. Let us now try to discover what raw materials it uses. Carbohydrates contain carbon, hydrogen, and oxygen (cp. p. 49), and hence these elements must be supplied by the materials used. Distilled water will provide hydrogen and oxygen, but not carbon. How is the carbon obtained? Leaves grow exposed to air, of which the composition in round figures is:

Nitrogen . . .	78 per cent.
Oxygen . . .	21 „
Carbon dioxide . .	0·04 „
Various rare gases .	a trace.

Can this mere trace of carbon dioxide be the source of the green plant's carbon and hence of all the carbon in the world's food? The following experiments help us to answer this question.

Experiment 13. Take two similar plants which have been kept in the dark until their leaves are completely free of starch. (Test a leaf from each plant.) Place these plants under bell jars, as shown in Fig. 11. Air can enter the jars freely, but in one case there is caustic soda under the bell jar and soda lime in the tube through which fresh air enters. The air in this jar is thus deprived of carbon dioxide.

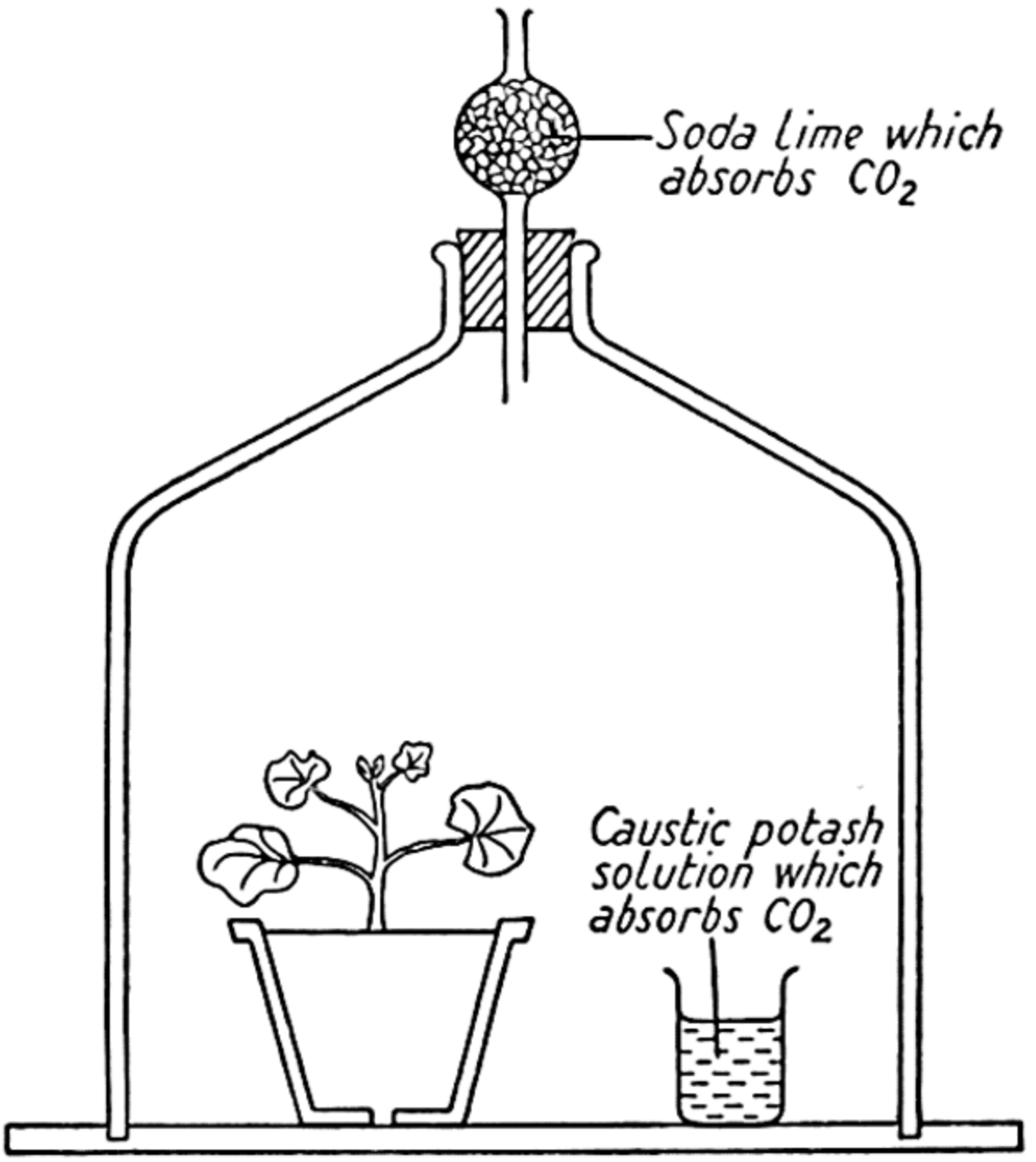


FIG. 11. Experiment to show that carbon dioxide is essential for photosynthesis

Leave both plants for a day or two, and then remove leaves at the end of a sunny day. Kill, decolorize, and test them with iodine. There is no starch in the leaves which have been deprived of carbon dioxide, but it is abundant in the control leaves.

CARBON DIOXIDE USED IN STARCH-MAKING. Obviously the carbon dioxide of the air is a necessary raw material for the

manufacture of carbohydrate food. A further experiment will show that the leaves actually absorb this gas.

Experiment 14. Take a tall gas-jar, put a little water at the bottom, and place some leaves with their stalks in this water (cp. Fig. 14). Now charge the jar with carbon dioxide, which, being a heavy gas, collects in the jar, driving the air out before it. Prepare a similar jar containing no leaves. Test the gas in each jar with a lighted splint. It goes out immediately; the gas no longer supports combustion. Cork up both jars tightly and leave on a sunny window-ledge until the next lesson. Again test the gas in each jar with a lighted splint. The splint remains alight and often burns more brightly than in ordinary air, in the jar containing green leaves. It goes out as before in the control apparatus.

The leaves have used up the carbon dioxide, and the jar now contains enough oxygen to support combustion. We must return to the source of this oxygen later.

Hence carbon dioxide and water are the raw materials used by the plant in starch-making.

THE SUPPLY OF ENERGY. Any ordinary factory requires power (energy) as well as raw materials. This is usually supplied as heat (from combustion), as electricity, or as water power, and it is well known that during a coal strike, or when the engines fail, the factory cannot work, however ample its supply of raw material. Where does the green cell obtain its energy? It is working just as truly as a factory, and must have energy to carry on its work.

Experiment 15. Partly cover some leaves which are still attached to the plant with strips of brown paper containing holes of simple design. The paper strip is doubled over the leaf lamina and firmly fixed in position with paper-clips (cp. Fig. 12, p. 63). Affix this shade one day and leave till the next afternoon. Then pick the leaf, kill, decolorize, and test for starch. This will be found in all parts that have been exposed to the light and nowhere else. We have made a 'starch print'. The holes in the paper are exactly reproduced on the leaf, each hole being represented by a patch, now dark in colour, because the cells under the hole contain starch, while the cells that have been shaded contain none.

We learn from this experiment that the green cell gets its energy from the sun; directly the light is withdrawn starch-

making (photosynthesis or carbon dioxide assimilation) ceases. The work of the chloroplast is apparently to absorb light-rays so that this energy may be available for the process of manufacture. The chief starch-making (assimilating) organ is the leaf, and since the energy used by its green cells comes from the sun, we understand why the lamina of a typical leaf is always flat (of large surface) and thin (cp. Fig. 23); why, further, shade leaves are often found to be thinner than similar leaves growing in the sun; lastly, why water-plants cannot grow in very deep water (which absorbs the sun's rays). *Light must reach every assimilating cell.*

GREEN COLOUR ESSENTIAL FOR ASSIMILATION. In all our experiments on assimilation we have used green plant tissues, and we can now understand why they alone carry out photosynthesis.

Experiment 16. Let us examine some variegated leaves at the end of a sunny day. We sketch the leaves to show the distribution of the green colour, then kill, decolorize, and test for starch as before. The distribution of starch exactly coincides with the distribution of green colour.

'Chlorophyll', says Sir A. Shipley, 'is the most wonderful substance in our world. Without it life as we know it would be impossible.'

> For life is colour and warmth and light
> And a striving evermore for these.

Our experiments have revealed many facts about the food-manufacturing process going on in green cells. *Carbon dioxide assimilation or photosynthesis* is the name given to this process, and by it the carbohydrates starch and sugar are made by green cells in sunlight. Let us summarize what we have learned concerning it.

1. It occurs in green cells only, the chloroplasts absorbing the necessary energy.

2. This energy must come directly from the sun (i.e. it cannot be stored); hence photosynthesis goes on only in the light.

3. Carbon dioxide and water are the raw materials used;

the assimilating plant obtains its carbon dioxide from the air.

4. Sugar is formed and the plant gains in dry weight.

5. Some of this sugar is transformed to starch for temporary storage.

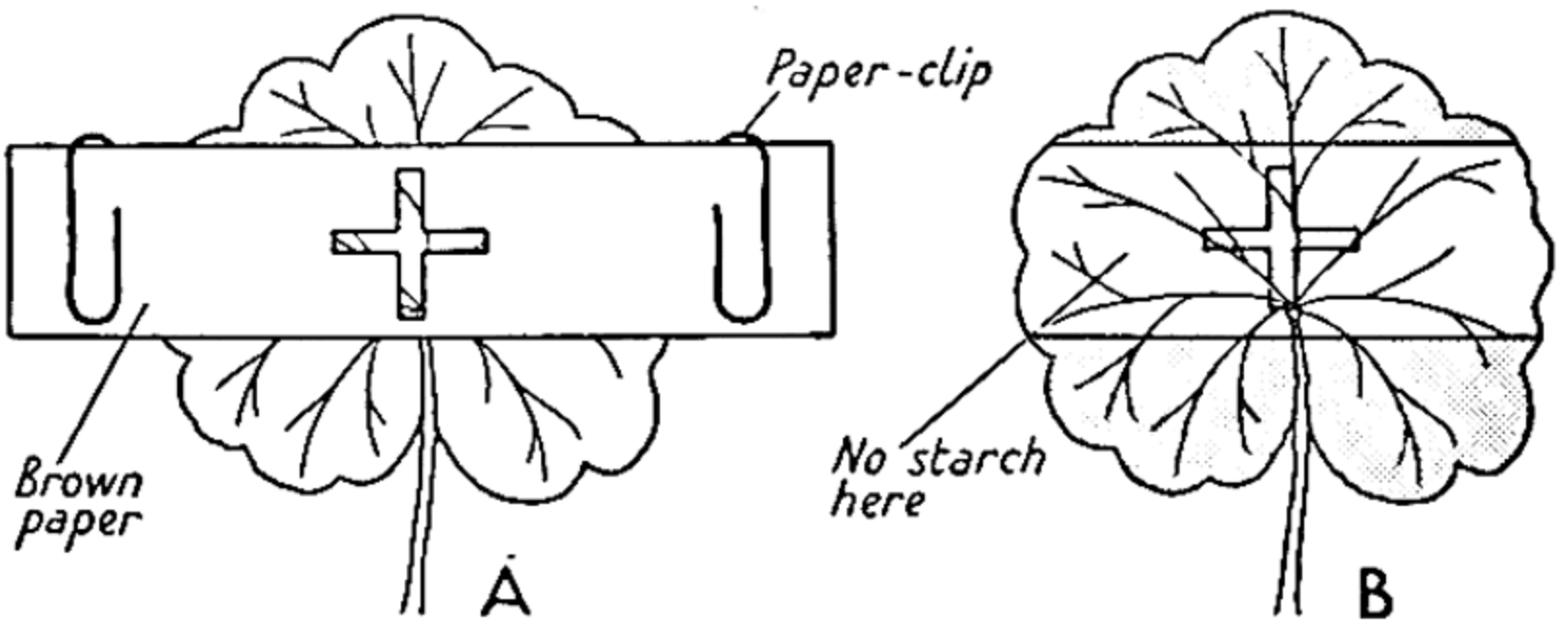


FIG. 12. Experiment to show that starch is only formed in those green cells which are exposed to light. (Expt. 15, p. 61)

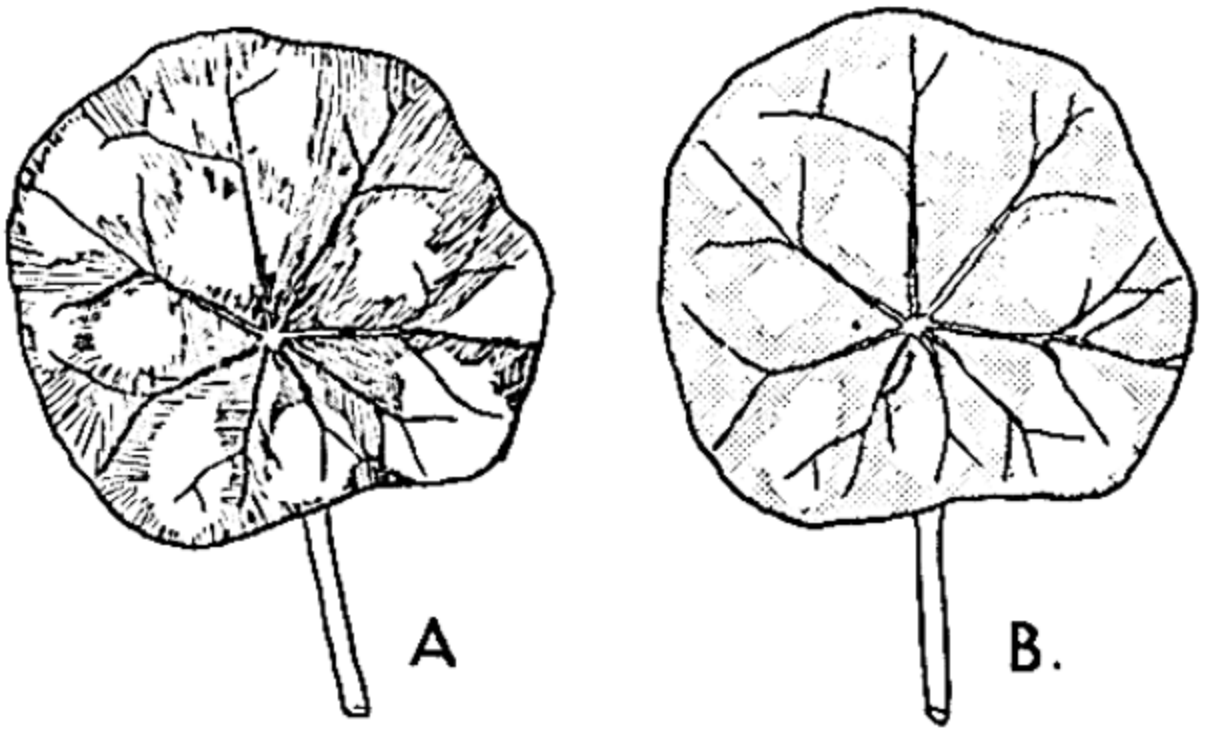


FIG. 13. Experiment to show that green colour is essential for photosynthesis. A. Fresh leaf of variegated garden nasturtium, green parts shaded (× ⅔). B. Same leaf, after iodine test. Shaded parts contain starch

6. Oxygen is set free as a waste product, assimilating plants giving off oxygen.

We shall return to demonstrate the last two points shortly. We do not yet know the full story of the actual method of manufacture. The carbon dioxide is apparently decomposed

by the living protoplasm and the carbon linked up with the water molecules to form a carbohydrate.

A glucose sugar might be formed thus:

$$6CO_2+6H_2O = C_6H_{12}O_6+6O_2.$$

This equation almost certainly represents the whole process in too simple a manner. A possible intermediate step is that suggested by the equations

$$CO_2+H_2O = CH_2O+O_2$$

and then

$$6CH_2O = C_6H_{12}O_6.^1$$

CH_2O is the simplest possible carbohydrate, formaldehyde. If it is actually an intermediate product in the process of sugar manufacture, it must be immediately transformed into sugar as shown above, for it is a poisonous substance and could not be allowed to accumulate in the protoplasm. However, theories about the actual chemical details of this process are not important for the beginner in biology. It is enough to realize that carbon dioxide and water are the raw materials used and that *sugar is the first stable substance to be formed as the result of photosynthesis.*

SUGAR TRANSFORMED TO STARCH FOR STORAGE. Sugar is soluble in water, and the amount dissolved in the protoplasm and the sap of assimilating cells would tend continually to increase while photosynthesis was in progress. This obviously could not go on indefinitely, and when the sap contains more than about 0·5 per cent. of sugar we usually find it being rapidly converted into insoluble starch for temporary storage, this conversion being the work of an enzyme (cp. p. 126). The process taking place may be expressed by the following equation:

$$nC_6H_{12}O_6 = (C_6H_{10}O_5)_n+nH_2O$$

n sugar molecules = one starch molecule + *n* molecules of water

The process is one of dehydration, since water is set free. We see why starch is so often found in actively assimilating cells. It has been called the first visible product of assimilation.

[1] This sugar molecule would contain 677·2 calories of locked-up (potential) energy.

THE SURPLUS OXYGEN. The equations given on the previous page show that water and carbon dioxide will, between them, provide more oxygen than is required for sugar-making, and experiment 14 has already suggested that the assimilating leaves may give off the surplus.

The fact that they do so is most easily demonstrated on a water plant, as it is easy to collect a gas over water.

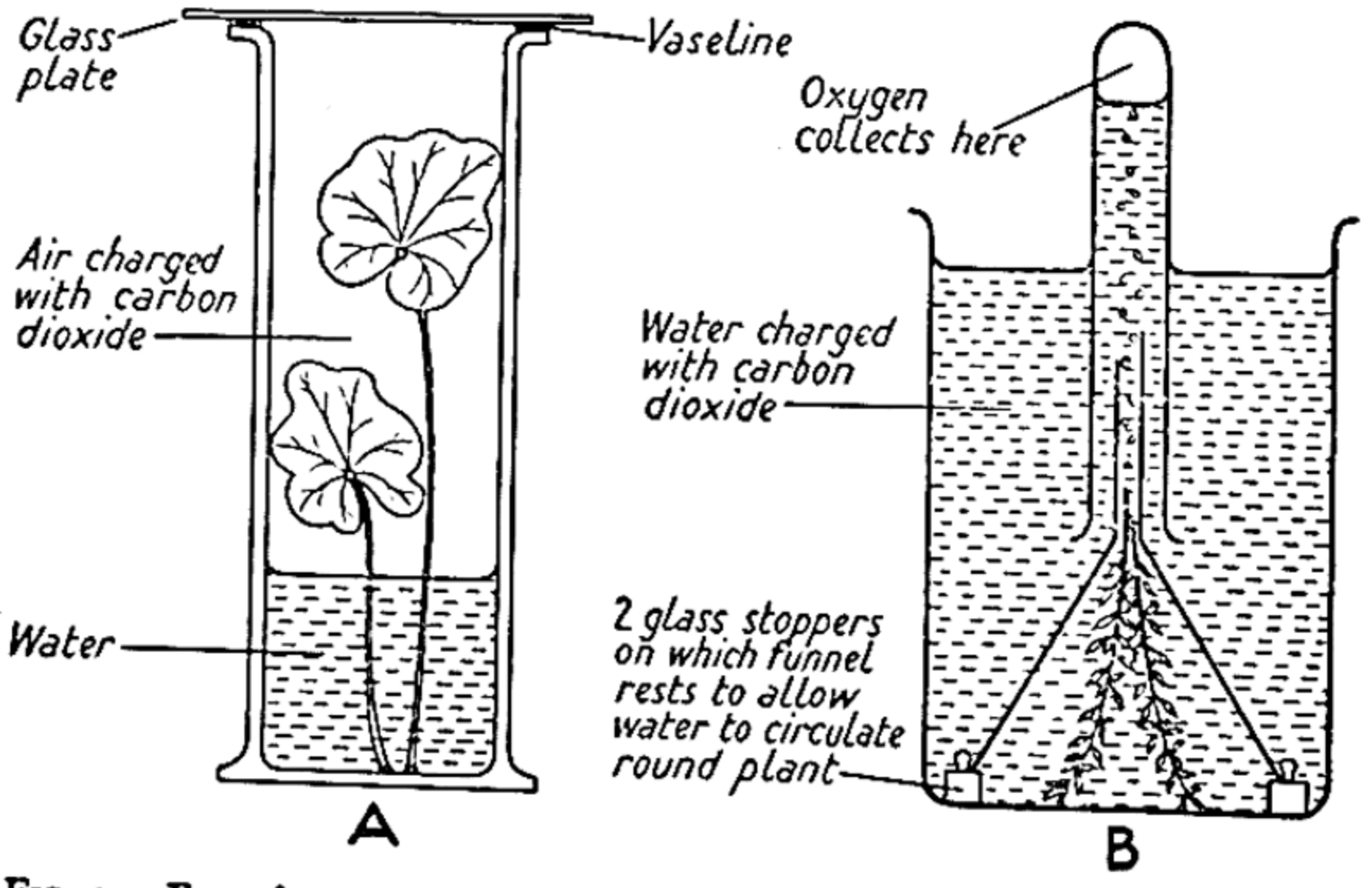


FIG. 14. Experiments to show, **A**, that carbon dioxide is absorbed and, **B**, that oxygen is given off during photosynthesis

Experiment 17. A beaker is nearly filled with tap water through which carbon dioxide is bubbled. We now place a funnel over a mass of Elodea or other suitable water-weed, immerse the whole in the beaker of water, and cover the end of the funnel with an inverted test-tube filled with water, as shown in Fig. 14. The funnel is raised to allow the water to circulate freely round the plant. The whole apparatus is now exposed to the sun or to a strong artificial light.

Bubbles of gas are seen to rise in the funnel and to displace the water in the test-tube. When sufficient gas has been collected it is tested with a glowing splint. Enough oxygen is present in it to cause the splint to break into flames. This shows that the water plant has given off oxygen.

TRANSLOCATION OF CARBOHYDRATE FOOD AFTER SUNDOWN. One fact disclosed by our experiments still remains to be explained. How is it that green cells that have been in the dark for some time contain no starch? (Cp. experiment 10.) It is because after sundown the stored starch is gradually turned back to sugar, this conversion being the work of an enzyme. (We shall have many other examples of enzyme activity in the course of our work; cp. Chapter XII.)

This sugar is soluble in water; it passes from cell to cell, and some of it reaches the leaf veins, through which it travels (in the bast; cp. Figs. 22 and 25) to other parts of the plant. The manufacturing cells are thereby emptied of their surplus at night and the factories are cleared ready for renewed activity at daybreak. If we remove a leaf at sundown from an actively assimilating plant and keep it in the dark with its stalk in water, we interfere with this process of *translocation*. The sugar cannot be conveyed away; hence such a leaf contains abundant sugar, as is easily shown by suitable tests.

QUESTIONS ON CHAPTER VI

1. Describe experiments by which you would prove that green leaves make food when exposed to light; say what you know of the nature of the food and the method of its manufacture.

2. Under what conditions is starch formed in plants? Explain carefully how you would demonstrate its presence. (J.M.B.)

3. Describe the changes which would take place in the air inside a closed vessel, containing green leaves, during exposure to sunlight. Account for these changes as fully as you can. (L.G.S.)

4. A green leaf is removed from a plant at the close of a sunny summer's day and another is removed next morning. What differences would you expect to find between the two leaves, and how would you demonstrate it? Account for the differences as fully as you can. (L.G.S.)

5. What is chlorophyll? Explain its supreme importance to organic life. (Ox. & C.)

6. What is photosynthesis, and where does it occur? What conditions must be fulfilled if the process is to take place? Describe two experiments in support of your statements. (L.G.S.)

7. Bubbles of gas are often seen rising to the top of an aquarium

in which green plants are living, especially when the sun is shining on it. Of what do these bubbles consist? Give an account of the process leading to their formation.

8. What are the functions performed by chlorophyll and light in the manufacture of food for the use of plants? Illustrate your answer by reference to experiments you have seen performed. (C.W.B.)

9. How would you show experimentally that a supply of carbon dioxide is necessary for starch formation in a green leaf? (C.)

10. What do you understand by photosynthesis (carbon assimilation) in plants? Why is this process of great importance in nature? How would you test for the products of photosynthesis in a green leaf? (L.G.S.)

11. How would you demonstrate the presence of starch in plants? What conditions are necessary for its formation? (Ox.L.)

12. Enumerate the conditions that must be present before photosynthesis can take place. Select any *two* of these conditions, and in each case describe carefully an experiment which demonstrates that this condition is essential. (J.M.B.)

13. What is photosynthesis? What experiments would you carry out to demonstrate the conditions under which it occurs? (L.G.S.)

14. In what parts of the plant are carbohydrate foods first made from inorganic materials? In what form, and by what route, do these foods travel about the plant? In what form are they stored as reserves? Describe any *two* plant organs in which different types of carbohydrate are stored. (J.M.B.)

15. Describe in detail two experiments by which you could show that (*a*) carbon dioxide is absorbed, and (*b*) oxygen is given off in the process of carbon assimilation. (Ox. & C.)

CHAPTER VII

THE SOURCE OF THE WORLD'S FOOD SUPPLY
(*continued*)

THE MANUFACTURE OF OILS AND FATS, PROTEINS, VITAMINS, BY PLANTS

FATS AND OILS. We have seen that carbohydrate foods owe their origin to green plants. Many plants also contain oil; large quantities are found, for example, in certain seeds; Brazil nuts contain 68 per cent., walnuts 52 per cent., coconuts 65 per cent., castor-oil seeds 24 per cent., sunflower seeds 38 per cent., and so on. Such seeds are often of considerable commercial importance.

Exercise. Test the above seeds for oil (cp. p. 54).

These oils are almost certainly formed from carbohydrates made during photosynthesis. The following figures illustrate this fact; they give the relative amounts of oil and carbohydrate in the ripening seed of the almond, and show that as the one increases the other decreases.

	Per cent. fat	*Per cent. carbohydrate*
June 9th . .	2	34·1
July 4th . .	10	23·2
August 1st . .	37	8·8
September 1st .	44	7·6

It is interesting to find that a similar change of carbohydrate to oil takes place in the leaves of evergreens as winter approaches; the carbohydrates reappear with warmer weather.

OILS AND FATS ARE MADE BY GREEN PLANTS. Plants make oils and fats as well as carbohydrates. These substances are not, as a rule, formed directly from carbon dioxide and water, but indirectly from some carbohydrate. The cells which bring about this change (e.g. the cells of the almond seed) are not always green cells, nor is the necessary energy derived directly

from the sun. We shall see later (Chapter XXI) how it is obtained. These oils are usually formed where food has to be stored; they occur as droplets in the storage cells, these drops being clearly visible under the microscope.

In certain minute floating plants which occur in enormous numbers in the surface waters of the ocean (constituting the plankton community), oil and not starch seems to be the usual end product of assimilation. This is probably connected with the fact that oil is lighter than water, starch heavier. If the plankton stored any quantity of starch it would have difficulty in keeping itself afloat.

ANIMAL FAT. Animals obtain all their food directly or indirectly from plants, and plant fat is often transformed into animal fat. Marine animals, for example, obtain oil from the plankton which is the ultimate source of so much of their food, and we find large quantities spread through the flesh of such typical sea creatures as herrings, whales, seals, and sea-gulls. The flesh of herrings may contain, in summer, from 40 to 50 per cent. of fat.

Most animals are not entirely dependent on plant fat, however, but can make it for themselves from carbohydrates; we ourselves make it from the starch of bread, potatoes, &c. Oxen may be fattened for market on grass alone, each beast requiring about an acre of good grass-land; about 46 per cent. of the body weight of such an animal consists of water (cp. Chapter III), the remaining 54 per cent. is solid substance; of this solid material, about 35 per cent. will be fat, 15 per cent. protein. Obviously certain cells in the body of the ox formed this fat from the foods, chiefly carbohydrates, which were supplied by the grass. The fat which we consume as butter, cream, &c., is manufactured for us by the cow in the same way.

Fat is the chief form in which animals lay up within their bodies a reserve of food which can be drawn upon in times of scarcity.

PROTEINS. We know (cp. Chapter III) that proteins are the chief constituents of protoplasm. In view of what we have learned already, we shall not be surprised to discover that *proteins*, like carbohydrates and fats, *are manufactured from simple inorganic substances by living plant cells.*

Since proteins contain nitrogen (p. 50) it is clear that water and carbon dioxide alone cannot serve as the raw materials for this synthesis. Where does the plant obtain the necessary nitrogen? At first sight the obvious answer would seem to be 'from the nitrogen of the air'. There is only 0·04 per cent. of carbon dioxide in the atmosphere, yet this mere trace supplies all the carbon wanted for photosynthesis. There is 78 per cent. of nitrogen. Surely this can supply the nitrogen that is required?

The argument is a plausible one, but it happens to be untrue. In 1860 the experiments of a great French scientist, Boussingault, proved finally and conclusively that the ordinary plant cannot use atmospheric nitrogen.

BOUSSINGAULT'S EXPERIMENTS ON THE SOURCE OF PLANT NITROGEN. He grew plants in the apparatus shown (Fig. 15). The soil was sterilized, and was shown by careful analysis to be quite free from nitrogen. Seeds were sown in the soil, and other similar seeds were analysed to see how much nitrogen they contained. In this way the amount of nitrogen present at the beginning of the experiment in each of the seeds used could be calculated.

The plants were given air containing carbon dioxide, supplies being constantly renewed by the tube *A*. The entering air was deprived of ammonia (a compound of nitrogen and hydrogen which often occurs as an impurity in air) by causing it to pass through sulphuric acid. There was also a device (*B*) for watering the plant, distilled water only being used.

Thus all the raw materials coming to the plant were absolutely controlled. The apparatus was placed in the light, and the plants were allowed to grow for several months. At the end of that time the nitrogen content of these plants was carefully determined by chemical analysis. *No increase in the amount of nitrogen was ever detected.*

The green plant cannot use atmospheric nitrogen; it is quite unable to tap that vast store. Any growth which had occurred in Boussingault's experiments had been at the expense of the nitrogen compounds stored in the seeds. When this supply was exhausted all growth ceased. This result, in view of the

prevailing 'economy of nature', is a very surprising one; nevertheless, it has been amply confirmed. Plants starve if given no other source of nitrogen than the nitrogen of the air.

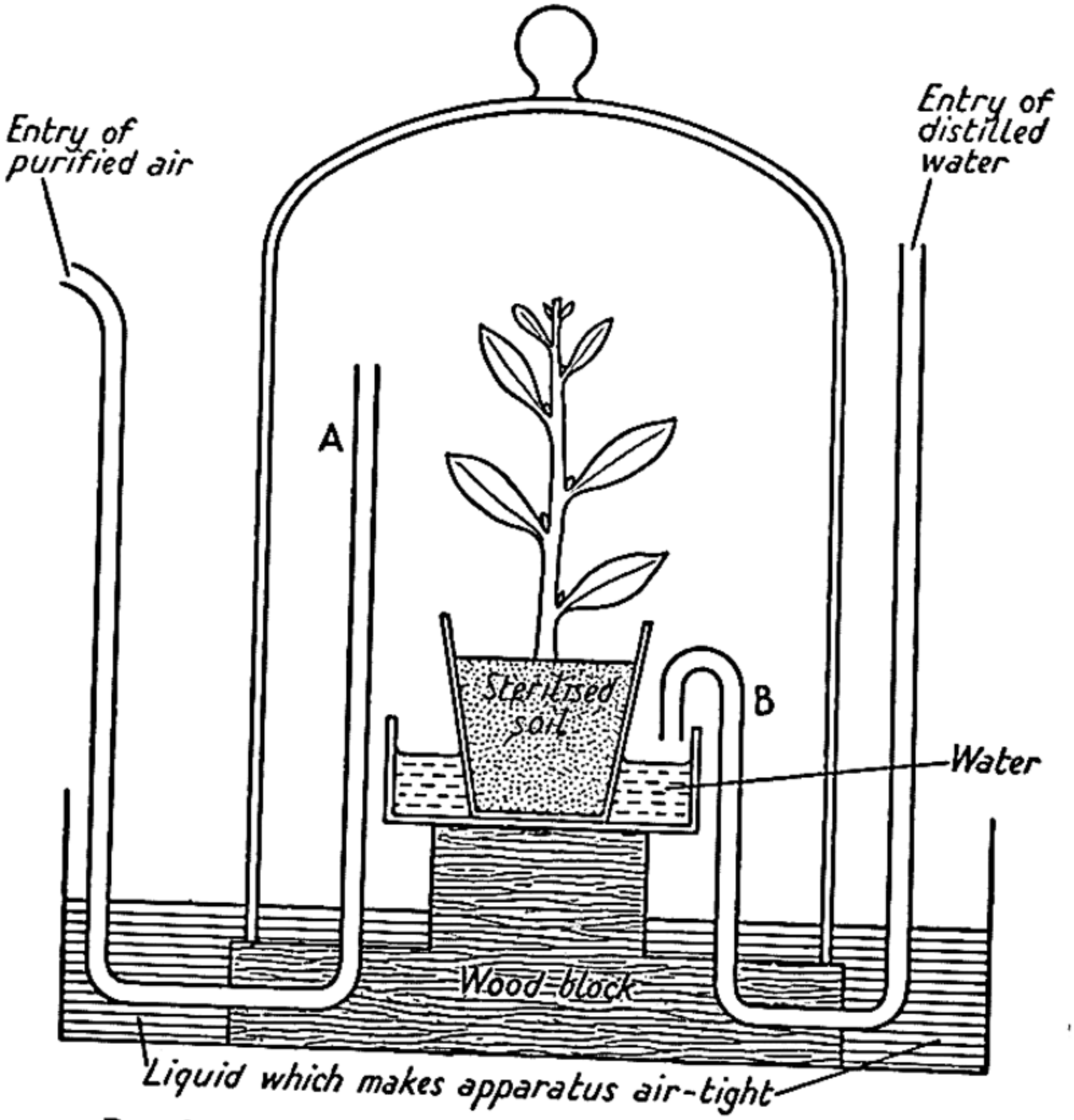


FIG. 15. Boussingault's apparatus, used by him to prove that plants cannot use the nitrogen of the air

THE SOURCE OF THE PLANT'S NITROGEN. If plants cannot use the nitrogen of the air, where do they obtain this essential element? It seems obvious that it must come from the soil. River water, pond water, and soil water are all similar in composition, and a solution which is very like natural soil water can be prepared as follows:

A COMPLETE CULTURE SOLUTION

Distilled water . . .	2 litres
Potassium nitrate . .	1 gramme
Ferrous phosphate . .	0·5 „
Calcium sulphate . .	0·25 „
Magnesium sulphate . .	0·25 „

This solution (*A*) contains only one salt of nitrogen, potassium nitrate. Make up a second similar solution (*B*) containing 1 gramme of potassium chloride instead of the potassium nitrate. If we grow two similar plants in solutions *A* and *B*, we see the result of growing one of them in a soil solution from which one of the usual constituents, namely, some soluble nitrogen salt, has been omitted. Such experiments are called water cultures.

A WATER-CULTURE EXPERIMENT.

Experiment 18. Take two large (2-litre) cleaned and sterilized gas-jars. Fill one with solution *A*, and the other with solution *B*. Choose two well-fitting corks. Each cork has a slot through which the plant can pass, and a hole to admit a glass tube. The cork is sterilized by passing it through a flame or by coating it with paraffin wax.

Suitable plants for these experiments are those that grow easily from cuttings (e.g. willow, Tradescantia, &c.) or seedlings containing no great reserve of stored food (e.g. sunflower, marigold, &c.).

If using seedlings the roots must be well washed with distilled water. Each plant is then fixed through the slot in the cork by a plug of cotton-wool.

The experiment can now be started. The jars are placed in a sunny window. Brown paper is wrapped round each to keep the roots dark. The solution should be aerated about once a week, a little air being pumped in through the glass tube. If the experiment continues for some time it is as well to lift the plants each month, to wash the roots thoroughly in distilled water, to clean the gas-jars and refill with fresh solution. The result of one such experiment is shown in Fig. 16.

We learn that plants starve if they are not provided with a suitable nitrogen compound; they cannot use the free element as it occurs in the air. The majority of plants require the



FIG. 16. Showing the result of a water-culture experiment (after Pfeffer). *a*. Without nitrates. *b*. Complete solution. *c*. Without iron; the leaves are yellow. The plant used was buckwheat

soluble salts of nitrogen called nitrates; a few can use ammonium salts. If deprived of these nitrogenous compounds plants cannot make proteins.

ASSIMILATION OF NITRATES BY PLANTS. We know very little about the actual method of protein manufacture; it is one of the trade secrets of the plant. It seems probable that some simple carbohydrate is first formed. A part of this is synthesized to sugar; the rest is combined with nitrates to form various intermediate products and, finally, proteins. Leaves are important centres of protein formation; but it is not yet known with certainty whether all plant cells have this power, or only green cells. Light is not required; if leaves are floated on a solution of sugar and nitrate they can make protein even in the dark; we conclude that, although light is essential for the synthesis of carbohydrates, it is not necessary for the later stages in the synthesis of protein.

VITAMINS. We have not exhausted the tale of the plant's synthetic activities. It also makes vitamins. This will be obvious from the list given on p. 53 of some of the materials in which vitamins are found. We know little, as yet, about the processes by which they are manufactured.

THE FORMATION OF PROTOPLASM. The final synthesis carried out by the plant is the formation of new protoplasm, which it makes if supplied with energy, and with water, carbon dioxide, nitrates, and other soluble salts. At least ten elements—the so-called essential elements—are necessary for healthy plant growth, and the omission of any one of them will stunt the plant and prevent its normal development. We may demonstrate these facts experimentally.

Experiment 19. Repeat the water-culture experiments, leaving out one or other of the essential elements. Replace potassium nitrate by calcium nitrate in one jar, and so deprive the plant of potassium. In another jar omit the calcium sulphate so that the plant can get no calcium. In a third, replace the ferrous phosphate by potassium phosphate and grow the plant in a solution containing no iron. Set up all these jars in the manner already described (experiment 18). Fill a control jar with the complete solution and another with distilled water only. Keep all the jars under similar external conditions and

record the growth, noticing the rate at which leaves unfold, lateral roots arise, when branch stems appear and so on, in the various jars.

If we omit any of the essential elements we find that we stop healthy growth and development. A most striking result is obtained by omitting iron; the plant becomes yellow and sickly, iron being necessary for the formation of chlorophyll.

THE SYNTHESIS OF FOOD BY GREEN PLANTS. Green plants are the sole manufacturers of organic foods from inorganic materials. Because of this work done by plants, animals are saved the necessity of making their own food. Obtaining it ready-made, they have more energy to spare for other activities.

'The animal can only raise the complex substances of dead protoplasm to the higher power, as one may say, of living protoplasm; while the plant can raise the less complex substances—carbonic acid, water, and nitrogenous salts—to the same stage of living protoplasm.' (Huxley.)

When we know these facts we look at the green plant with different eyes. Scientists, by experiments similar to those we have described, have wrested from it some of its secrets. Much remains to be learned. We may well echo the words of Tennyson:

> Flower in the crannied wall,
> I pluck you out of the crannies;—
> I hold you here, root and all, in my hand,
> Little flower—but if I could understand
> What you are, root and all, and all in all,
> I should know what God and man is.

'But even the plant has its limitations. A plant supplied with pure carbon, hydrogen, oxygen, nitrogen, sulphur, and the like would infallibly die . . . though it would be surrounded by all the constituents of protoplasm.' (Huxley.)

QUESTIONS ON CHAPTER VII

1. What do you know of (*a*) the composition of oils and fats, (*b*) their manufacture in the bodies of plants and animals? How would you test a seed for the presence of oil?

2. Give a list of (*a*) the chief plant fats, or oils, (*b*) the chief animal fats (or oils) known to you which are articles of commerce, and say what you know of the use to which each is put.

3. What do you know of (*a*) the chemical composition, (*b*) the method of manufacture, of proteins? From what foods do British people usually obtain the proteins they require?

4. What do you understand by a 'water-culture experiment'? Describe in detail how you would set up and carry out such an experiment, and what you would expect to learn from it.

5. What is a complete culture solution? Give its exact composition, and show how you would demonstrate that each ingredient is necessary for the life of the plant.

6. Give a list of the elements always found in living matter. Explain why carbon is the only one of these elements which is not supplied by a complete culture solution.

7. Describe how you would prove that green plants cannot make use of the nitrogen of the air.

8. What substances does the root take from the soil? What use does the plant make of them? (B.)

9. Enumerate the principal minerals which constitute the raw materials of plant food. How would you proceed to show which of these are essential for the full development of the plant? (C.W.B.)

10. How do plants obtain their food? Of what substances does this food consist? In what ways does it differ from the food used by animals? (C.L.)

11. From what sources and by what methods do living organisms get nitrogen? Give definite examples. (C.L.)

12. Nitrogen is a constituent of all living matter. Explain (*a*) how plants and animals obtain their respective supplies of nitrogen and (*b*) what becomes of this nitrogen after it has entered the living organism. (C.L.)

13. What are the injurious effects of removing the leaves from an actively growing plant? Why are the leaves of plants essential for animal existence even though many animals do not eat them? (Ox.L.)

CHAPTER VIII

HOW RAW MATERIALS ENTER PLANT CELLS: DIFFUSION AND OSMOSIS

ENTRY OF RAW MATERIALS. We have learned that green plants make the food of the world, the process of manufacture starting with the synthesis of carbohydrates from carbon dioxide and water. Later other raw materials, e.g. nitrates, sulphates, and other salts, are required for the manufacture of proteins. We must now ask how these substances pass into the cells. Obviously they must penetrate the cell-walls, since in these there are no apertures through which solid substances can enter.

To show that certain substances dissolved in water can pass through the walls of plant cells we set up the following experiment:

Experiment 20. Add some methylene blue to water in a watch-glass until the water is tinged faintly blue. Immerse some living Spirogyra filaments in it and leave for two or three days. Then mount the filaments in water and examine with a microscope. We find that some of the colour has passed into the cells and has become concentrated there. The liquid in the vacuole is quite blue.

The methylene blue has passed into the Spirogyra cells—but how? What force sets it in motion? What makes these molecules force their way through the cell-wall and the protoplasm? We can only answer these questions by considering the conditions in a solution.

GASEOUS DIFFUSION. We know that a gas (coal gas, ammonia, &c.) escaping at one point in a room will soon spread through the whole building, even if the air in that building is quite still. On this fact depends the efficacy of gas-attacks in modern warfare.

This phenomenon is known as *diffusion*. The molecules of any gas are in continuous motion. They constantly collide with each other and with the walls of any vessel in which they are enclosed. This causes them to spread out (diffuse) through

any space in which they are liberated. In a mixture of gases, such as air, the molecules of the different ingredients of the mixture diffuse quite *independently of one another*, from places where they are more concentrated to points of lesser concentration. The final effect of this diffusion, in which each substance moves at a different rate, is to disperse all the gases of the mixture evenly.

DIFFUSION OF SOLUTES. The molecules of a dissolved salt are likewise in motion, and they spread out through any liquid in which they are dissolved. This is easily demonstrated by a simple experiment:

Experiment 21. Wash a lump of copper sulphate, put it at the bottom of a tall gas-jar; fill this to the brim with water, cover it with a glass plate, and leave the apparatus undisturbed for some weeks. The copper sulphate dissolves and the blue ions (cp. p. 40) gradually spread upwards through the water. If left long enough the whole liquid becomes uniformly blue. (If possible, the temperature should be kept constant during this experiment, to prevent more rapid movement due to convection currents.)

Diffusion causes the molecules of every such dissolved substance to spread out evenly through the solvent.[1] If there is more than one substance in solution, these all become equally dispersed. Furthermore, if two different aqueous solutions are in contact, diffusion of crystalloids will take place across the surface between them until all the dissolved substances are scattered evenly through the solvent.

Thus there are molecular forces in solutions which might cause dissolved crystalloids to enter plant cells. Outside the cell is the soil solution, inside the sap. The two are of different strength, have different substances in them, and if they were in contact diffusion would take place. But in plants we are not dealing with simple diffusion, for the molecules in the soil water have to pass through two membranes before they can reach the sap. Consider the conditions under which the

[1] One striking difference between crystalloids and colloids (cp. p. 40) is that the former diffuse rapidly, while in colloidal solutions there is practically no diffusion.

methylene blue entered the Spirogyra cells in experiment 20. It had to pass through both the cell-wall and the protoplasm.

DIFFUSION THROUGH A MEMBRANE. We must therefore try to discover how the process of diffusion is modified by the presence of such membranes. Suppose, for example, we inserted one across the gas-jar used in experiment 21, so that the dissolved copper sulphate was below the membrane, pure water above. What would be the effect? This would obviously depend on the nature of the membrane. If it were quite *impermeable* to both the water and the dissolved salt, there could be no further exchange between the two liquids. If it were *permeable* to both, diffusion would proceed as before, until the whole liquid was a solution of equal strength, i.e. until the particles of the dissolved substance were dispersed equally through it; the only effect of the membrane would be a possible slowing up of the whole process, due to the fact that the particles must penetrate it.

SEMI-PERMEABLE MEMBRANES. OSMOSIS. But suppose the membrane were permeable to the smaller water molecules, but impermeable to the larger molecules of the dissolved substance. Such a membrane is described as *semi-permeable* to that substance. We find under such conditions that water passes rapidly through the membrane into the solution. This passage of water across a semi-permeable membrane from a weaker into a stronger solution is called *osmosis*. We may study the process by the following experiments:

Experiment 22. To illustrate the laws of osmosis, take a Whatman's diffusion shell (or use a piece of pig's bladder tightly stretched and fixed over the end of a thistle funnel). Soak the shell until soft, and fit it with a rubber stopper carrying a long length of glass tubing. Fill the shell with strong sugar solution (diluted treacle answers well), insert the stopper carefully, and bind the joint tightly with cotton. Rinse under the tap to remove any sugar that has escaped. Now mark the level of the solution in the glass tube and immerse the diffusion shell in a beaker of water.

The level of the liquid begins to rise at once, and in the course of a few hours it will have risen several feet. When the tube is nearly full, watch to ascertain that the level is still rising; if you now remove the beaker of water and replace it with a beaker full of a very

concentrated sugar solution, you will find that the level begins to fall and that this fall is continuous.

Experiment 23. An excellent membrane for osmosis experiments can be prepared in the following way. Take a porous pot, immerse it in boiling water; take it out and, while still hot, fill it with melted hectograph jelly. Move the jelly about until a film has formed over the inner surface of the pot, and then pour out the remainder.

Now fill the pot with treacle, insert in it a stopper carrying a long glass tube, making the joint between stopper and porous pot tight with rubber solution. Immerse the pot in water, as in the previous experiment, and observe the rise (often of many feet) due to water entering the pot by osmosis. After some time test to see if any treacle (sugar) has escaped into the surrounding water.

These experiments show us that water always passes by osmosis from the weaker into the stronger solution. By diffusion, on the other hand, the substance spreads out from places where it is more concentrated to regions of lesser concentration, i.e. from the stronger into the weaker solution. These differences should be carefully noted. The process of osmosis dilutes the stronger solution, so that in this way (and not as in diffusion) the two become more equal in strength. The next experiment illustrates the process of osmosis in plant cells.

Experiment 24. Peel a potato and cut it into thin slices of approximately equal thickness. Gently wipe the outside of each slice with filter paper. Now weigh out two sets of slices (*A* and *B*) of equal weight. Immerse set *A* in tap water and set *B* in strong salt solution. Leave both sets for an hour; then dry as before to remove surplus moisture and weigh again. Set *A* has gained in weight and the slices are stiff (*turgid*). Set *B* has lost in weight and the slices are soft and pliable (*flaccid*). Water has obviously passed into the cells of *A*, increasing both their weight and turgidity. But something has passed out from the cells of *B*, as these slices have lost both weight and rigidity.

DIFFUSION AND OSMOSIS, A SUMMARY. The above experiment shows that plant cells can only absorb water under certain definite conditions. If the soil solution is too strong, water may actually be sucked out of the cells; for this reason over-manuring, especially with easily soluble artificial manures, can do positive harm.

There are two processes by which raw materials enter plant

cells. Salts enter by diffusion through the membranes (cell-wall and cytoplasm), which are permeable to these substances. Such diffusion takes place whenever two solutions containing different crystalloids (or the same crystalloid in different strengths) are in direct contact or only separated by permeable membranes. Water enters largely by osmosis, for the protoplasmic membrane is impermeable to many of the manufactured foods (e.g. sugar) which are present in the sap, and thus acts as a semi-permeable membrane. Osmosis occurs whenever two solutions of different strengths are separated by a membrane impermeable to at least *one* of the dissolved substances; water passes from the weaker into the stronger solution, diluting the latter and tending to make the two solutions equal in strength.

No general rule can be given for the permeability of either the non-living cellulose wall or of the living protoplasm of the cell. In particular, the permeability of the protoplasm is not fixed, changing with varying conditions; it is so responsive to its environment that its permeability to any given substance may be strikingly different even in different parts of the same cell.

Experiment 25. To illustrate the effect of a change in the permeability of the protoplasm caused by killing it, take three rods of uncooked beetroot; about 3 inches long and 1 square inch in section is a suitable size. Wash the rods to remove any sap (this is red in beetroot) which may have exuded from the cut cells. Immerse one rod in tap water, the second in a strong sugar solution, the third in boiling water. The first becomes stiff and turgid; the second limp and flexible. This is just what our previous experiments would lead us to expect. Notice that no colour escapes from the beetroot cells in either case. From the third rod some red colour passes out into the surrounding water. The beetroot becomes pale in colour and the water is quite red.

So long as the protoplasm is alive it is impermeable to this colour. Killed by the hot water, its permeability changes, and the red pigment dissolved in the sap diffuses out into the surrounding water.

Thus the entry of dissolved substances into plant cells (and only substances in solution *can* enter) is controlled and regulated by the permeability of the living protoplasm. Different plants will not all take up the same substances even from the

same soil solution. This power of selection depends on the varying permeability of different samples of protoplasm.

QUESTIONS ON CHAPTER VIII

1. What substances are found dissolved in soil water? Say what you know of the process by which these substances penetrate into plant cells.

2. What is meant by osmosis? Describe an experiment to illustrate your answer, and discuss the importance of osmosis to living organisms. (L.G.S.)

3. Some young rather limp seedlings are immersed in strong salt solution, while other similar seedlings are placed in tap water. Describe the changes which would occur in the seedlings, and explain the reasons for these changes as far as you can.

4. Explain carefully how the substances which a plant obtains from the soil enter the body of the plant. What do you understand by water-culture experiments, and what are they designed to show? (J.M.B.)

5. Dry bean seeds are dropped into an aqueous solution of methylene blue. In some hours the seeds have doubled in volume, but when the skin is cut open no dye has penetrated. What light does this experiment throw on the method of entry of water into the seed? (J.M.B.)

6. Describe fully how water and mineral salts enter the plant. Include in your answer a description of an experiment illustrating the method of water absorption, pointing out those parts of the plant which correspond to the parts of the apparatus. (J.M.B.)

7. The ash of a dried grass is found on analysis to contain more silica than any other substance. Account for the presence of silica, and explain how you would propose to test experimentally whether silicon is essential to the growth of the grass. (J.M.B.)

8. (i) A variegated leaf, red and green in colour, retains its colour in cold water, but when the water is raised to boiling-point the leaf becomes green all over whilst the water takes on a red tinge. Explain this colour change. (ii) The boiled leaf is transferred to alcohol, and a green alcoholic extract is obtained whilst the leaf becomes colourless. Explain these facts. (J.M.B.)

9. Sketch and briefly describe the various parts of a single cell of Spirogyra. What conditions are needed for the healthy growth of this plant? How do essential substances enter the cells? To what uses are these substances put? (C.L.)

CHAPTER IX

THE ABSORPTION OF RAW MATERIALS AND THEIR PASSAGE THROUGH THE PLANT

LAND AND WATER PLANTS. When considering the way in which different plants absorb their raw materials, we must first of all distinguish between the plants which live immersed in water and those which are exposed to the air.

Aquatic plants obtain everything they require from the medium in which they live. The gases of the air are all soluble in water, carbon dioxide being particularly so; the necessary salts are likewise soluble, and all raw materials enter such plants in solution, the whole surface of the plant being absorptive.

These aquatic plants are of two kinds. The true aquatics are the *algae*, a group to which all seaweeds (red, brown, and green) belong, as well as many simple freshwater plants (e.g. Spirogyra). Some of these algae are very large, but their structure is always comparatively simple. If you examine a group of seaweeds, for example, you will see that they never possess roots or leaves; such organs are characteristic of land plants only.

Hydrophytes. Among the higher plants there are a certain number, called hydrophytes, which live in water, though their ancestors almost certainly lived on land. Some of these flowering plants (e.g. pondweed, Elodea, bladderwort, &c.; cp. Figs. 46, 79) live completely submerged; such plants absorb through their whole surface, as do the algae. Others (e.g. water-crowfoot; cp. Fig. 79), water-lilies, &c.) have some of their leaves above the water or floating on its surface. The under-water parts of these plants, like the algae, have an absorptive surface; the parts exposed to the air, on the other hand, behave like those of land plants.

In *land plants* there is no absorption through the general surface, for it is almost impervious to both liquids and gases. We have only to leave an aquatic plant out of water for a short time to discover how quickly it shrivels owing to loss of water. This rapid loss by direct evaporation from its surface is prevented in land plants by the layer of cutin which is developed on the outer walls of the epidermal cells (cp. Fig. 24). Nothing

can pass freely through this cuticle, either into the plant or out of it. Hence these plants need special structures to facilitate the entry of raw materials. They live, as it were, in two worlds. There is the root system, living underground and provided with root-hairs (cp. Figs. 2, 19) by which they absorb the soil solution. The shoot system is aerial, and differs markedly in form from the root (cp. Fig. 2). The surface layer of cells (epidermis) of its green parts, i.e. of its leaves and young stems, is, because of the cuticle, almost impervious, but it is pierced by minute apertures called stomates through which gases (e.g. CO_2) can enter by diffusion. These openings are shown in Fig. 24.

The raw materials, entering thus at opposite ends of the plant, have to be brought together in the green cells, where they are required for photosynthesis. We find there is a well-developed conducting system (cp. Figs. 2, 21, 22), which provides for the rapid transport of water and dissolved substances from one part of the plant to another.

The structure of the land plant is thus more complex than that of the typical aquatic. We turn now to examine this structure in more detail, with special reference to these methods of absorbing raw materials. It is best to begin with the young plant and to study the development of its various organs.

THE BROAD-BEAN PLANT

FRUIT AND SEED. The broad-bean seed is formed within a pod (cp. Fig. 17 A). This pod is a part of the parent organism, that is, of the plant which produced the seed. When ripe the seed becomes separated from its parent, and after a resting period is ready to start a separate existence. It is encased in a creamy seed-coat or testa; a dark scar, the hilum, marks where it becomes detached from the pod. Within the testa is the young plant, which at this stage is called an embryo.

Exercise. Examine and make sketches of the seed and of the contained embryo.

The embryo plant shows the following structures:

1. A white pointed radicle, from which the future root system will develop.

2. A minute plumule, lying between the cotyledons, from which the whole shoot system of the plant will be formed. With the aid of a lens we may, even now, discern a few leaf rudiments at its apex.

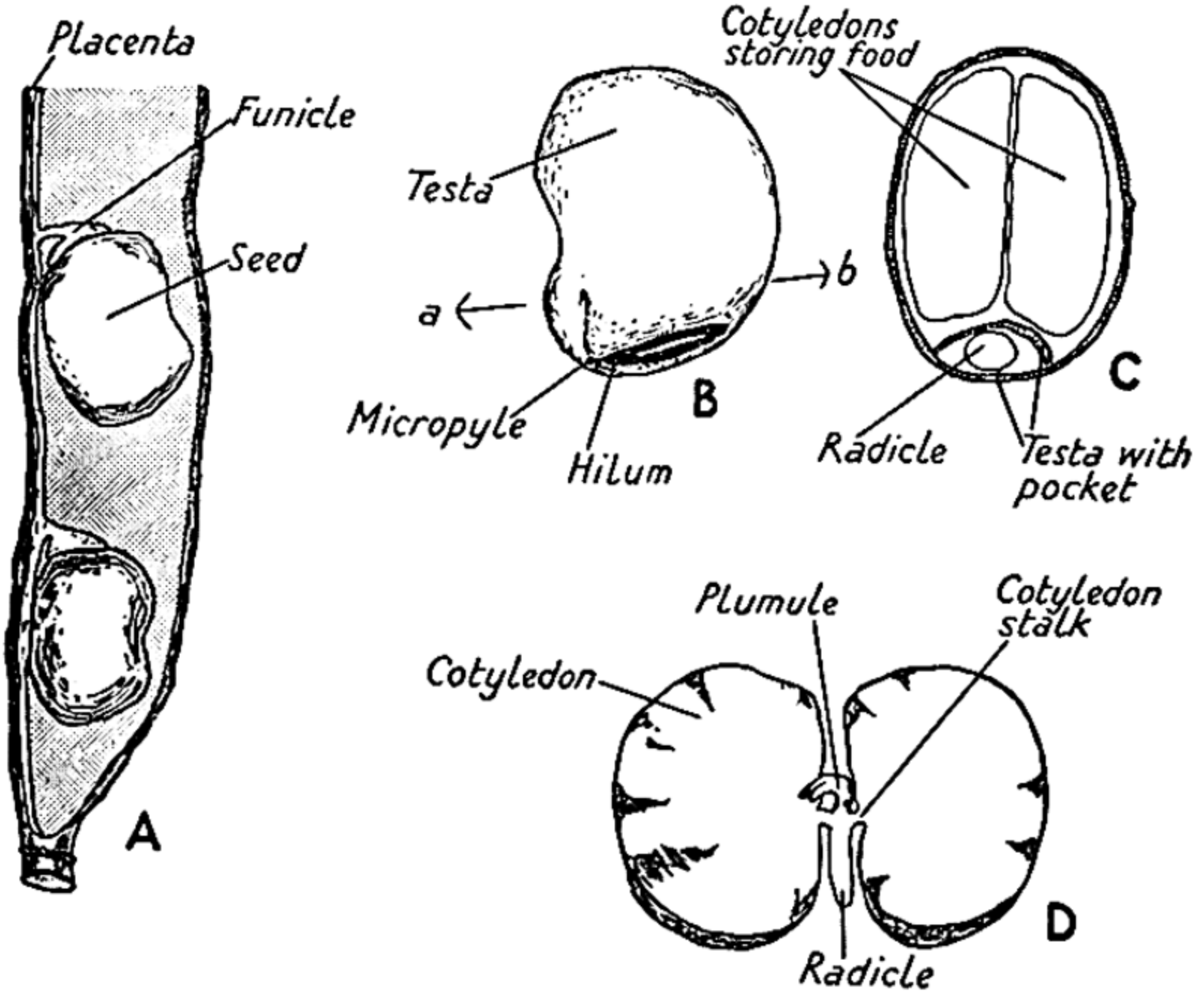


FIG. 17. A. Part of fruit of broad bean opened to show attachment of seeds. B. Broad-bean seed. C. Section of the seed at *ab* in B. D. Embryo plant removed from seed and opened out

Radicle and plumule together form the axis of the young plant.

3. Two large creamy cotyledons, stored with food (test and see what foods are contained). These are short-lived organs only useful to the embryo, and they fall off when their reserve of food is exhausted.

Exercise. Examine under the microscope a thin section cut from a cotyledon. The cells contain a large number of starch grains and also minute protein granules (cp. Fig. 18, p. 86).

GERMINATION. Given suitable conditions (cp. p. 354) the seed germinates and the embryo plant emerges. The radicle escapes first; it pushes through the testa near the micropyle and grows downwards. The cotyledon stalks then elongate and gradually pull the plumule from between the cotyledons. The testa splits still further; the plumule is soon quite free

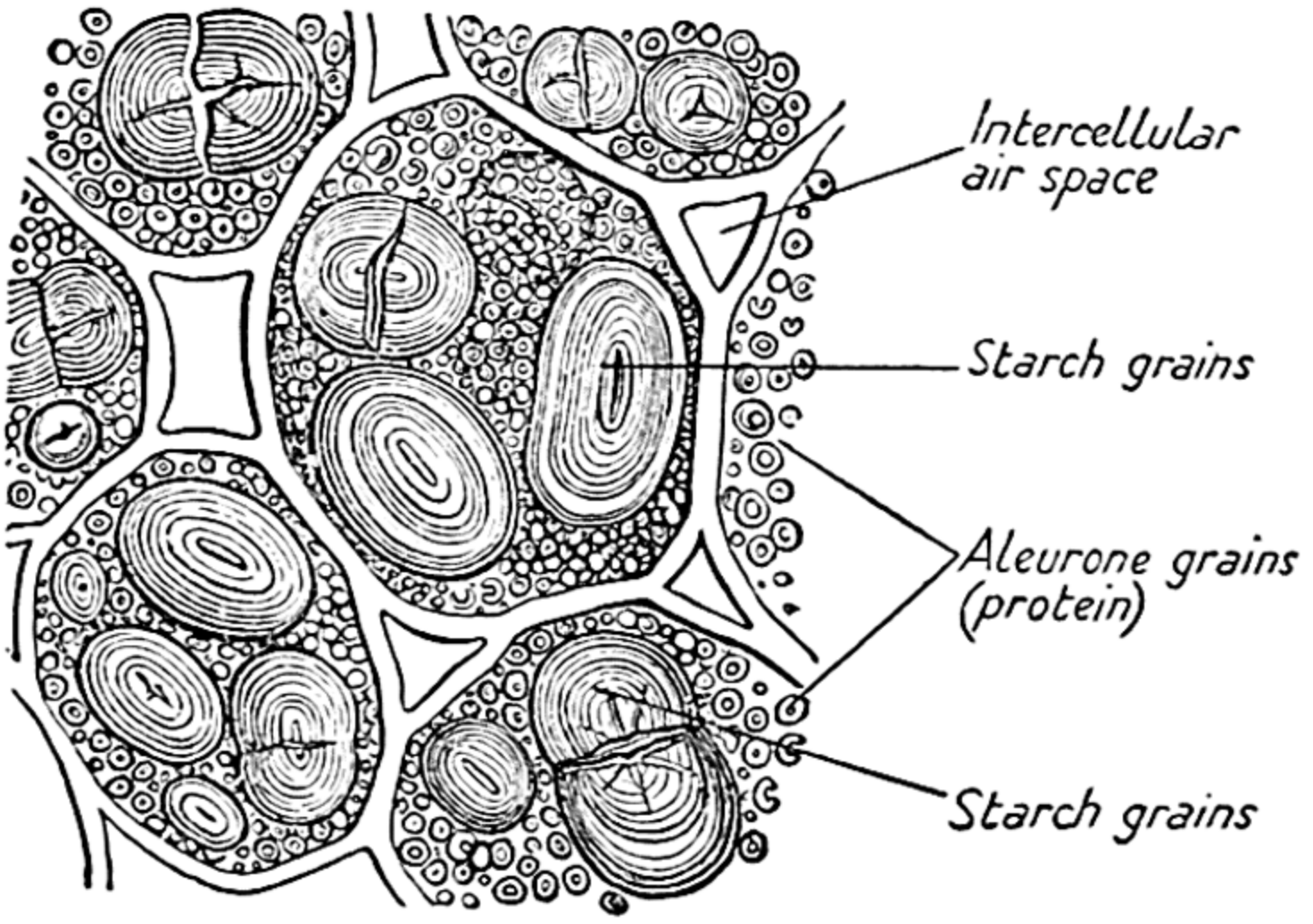


FIG. 18. Cells of a very thin section through a cotyledon of the embryo in a ripe seed of pea. (After Sachs)

and begins to grow upwards, forming the stem of the young plant. The cotyledons remain underground inside the testa, gradually withering as the young plant grows. The plumular hook (cp. Fig. 19 A and B) straightens; foliage leaves are formed and begin to unfold. The first two are very simple structures, the third more complex, resembling the leaves of the mature plant. The embryo has become a seedling.

Exercise. Grow some bean seeds and make a series of drawings showing consecutive stages in the process of germination.

THE ROOT SYSTEM OF THE SEEDLING PLANT.

Exercise. Examine the young root (radicle) of a seedling plant and verify the following facts:

1. The root is a smooth colourless tapering cylinder; its end is

quite bare. (The microscope reveals that the extreme tip of this apex is covered by a protective root-cap.)

2. Behind the bare apex is a region covered with numerous fine root-hairs.

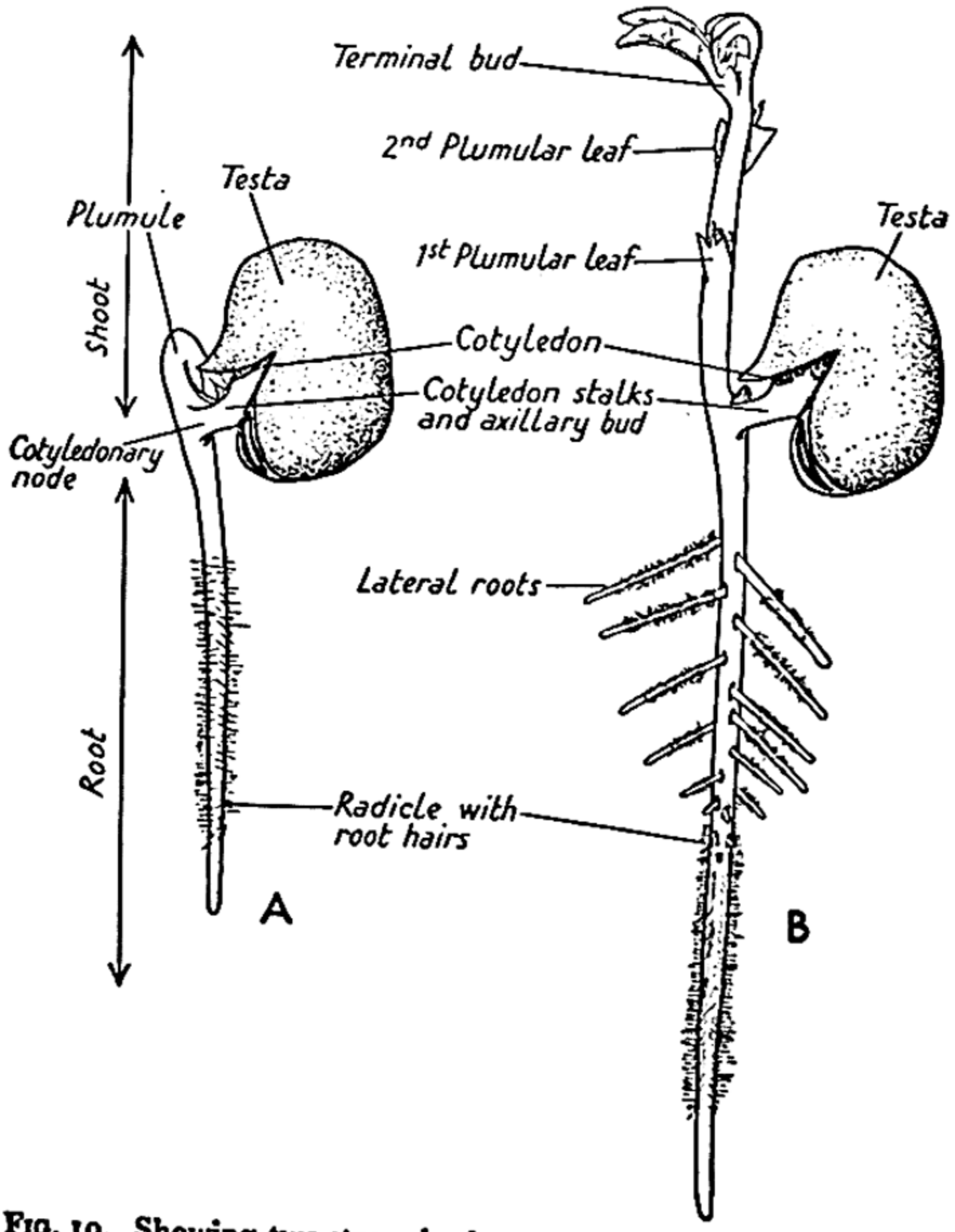


FIG. 19. Showing two stages in the germination of the broad bean (somewhat reduced)

3. Beyond this is the region of lateral roots. These arise endogenously (i.e. from within) as outgrowths of the main root and are like it in structure (cp. Fig. 19 B). They are in four rows, corresponding to the four groups of wood inside the root, opposite to which they arise (cp. Fig. 2).

Every root system, however large it may become, is formed on the same plan. Since their functions are alike it is not surprising that all roots are very similar in structure. This will become clear if you examine and draw the roots of any plants that are available.

THE SHOOT SYSTEM.

Exercise. Sketch a broad-bean plumule which is about 12 inches long and confirm the following facts:

1. The axis of the shoot is an ascending tapering cylinder, green in colour.

2. The apex is enveloped in a number of young immature leaves; the whole structure is known as the terminal bud.[1]

3. Lower down the stem the leaves are less crowded. Between them are definite lengths of stem called internodes. (Notice the first two foliage leaves, which are smaller and simpler than those formed later.)

4. The leaves arise at the nodes and are arranged in a definite order; in each leaf axil there is an axillary bud. These buds may grow out into branch stems which are similar to the main stem in structure.

VARIATIONS IN THE STRUCTURE OF THE SHOOT. Shoot systems are much more varied in structure than are roots. In some the axis is so short that it hardly rises above the ground, and leaves are crowded on it without internodes. The daisy and dandelion are plants of this type, which are called rosette plants. On the other hand, the shoot system may become very large, as it does in our great forest trees—oak, beech, ash, pine, &c. These great differences of structure enable flowering plants to live under very varying conditions. The rosette plant can withstand tempestuous winds which would bend, break, and eventually kill any young tree. On the other hand trees, once established, occupy vast areas of ground and cast so dense a shade that many competitors are excluded from any area they may make their own.

[1] A bud is simply a stem apex covered with partly developed leaves which are closely packed round the apex, thus protecting each other and the delicate stem-tip on which they were produced. A Brussels sprout should be examined to obtain a clear picture of the structure of a bud.

Under all these variations of shoot structure we may always recognize in the young plant the following elements: stems, each ending in a terminal bud and divided into nodes and internodes; leaves arranged in a definite order, axillary buds, and branches, all of which are found at the nodes of the stem.

Exercise. Before going farther the student should draw the shoots of any available plants to confirm the facts mentioned.

THE ROOT, AN ORGAN OF ABSORPTION.

Experiment 26. To show that the root absorbs water and to measure roughly the amount absorbed by one broad-bean root in a given time, we fix a seedling plant by means of a split cork or a plug of cotton-wool in the mouth of a measuring cylinder. Its roots dip into water, which nearly fills the cylinder. When the plant is in position cover the top of the water with a little olive-oil; this prevents direct evaporation from the surface. Set up a second similar control apparatus with water and oil but no plant. Note the height of the water and read the levels daily for some weeks. The level falls continually in the cylinder containing the plant but not in the other. The fall is due to absorption by the root, and we can read off the amount absorbed. We must, however, remember that the reading is only an approximate one, as we have made no allowance for any growth of the root.

THE ROOT-HAIR, THE CHIEF ABSORBING ORGAN. The cells of the skin (epidermis) of the young root-tips are the chief organs of absorption. The surface area of the root is enormously increased by the development in this region of large numbers of root-hairs.

Exercise. Remove a root-hair, mount it in water, and examine it under a microscope.

Each hair is a tubular outgrowth of a single epidermal cell. Such hairs, produced near the apex of every branch of the root, provide an enormous surface through which the soil water can pass. One observer estimated that there were as many as 232 root-hairs growing on every square millimetre of surface of the roots of some pea seedlings. The root-hair is bounded by a thin cell-wall lined with protoplasm; its centre is occupied by one or more vacuoles containing sap. In its

relation to water the hair behaves rather similarly to the diffusion shell described in experiment 22, the cell-wall being a permeable membrane, the protoplasmic lining a semi-permeable one. It threads its way between the soil particles

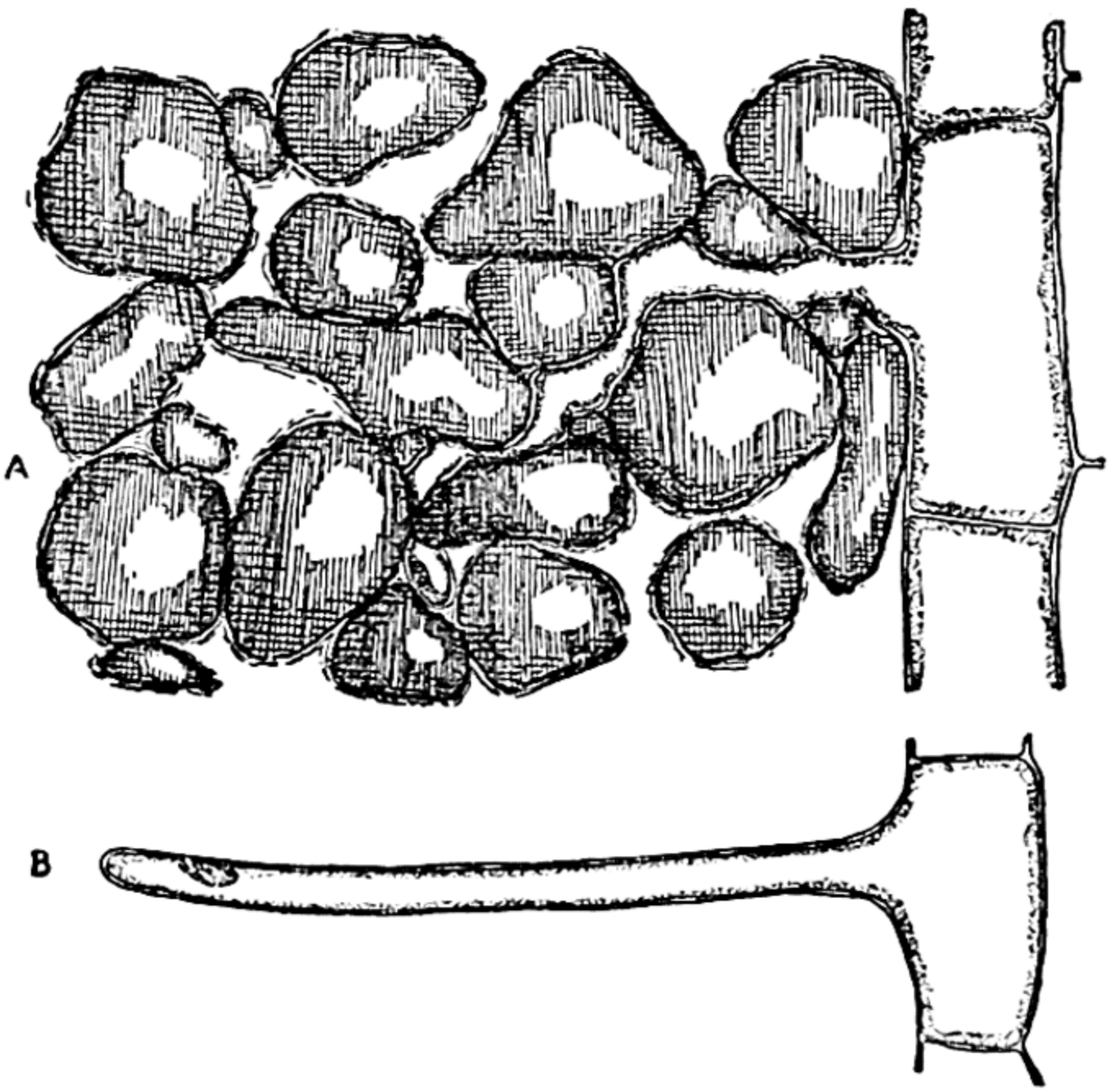


FIG. 20. **A.** Root-hair among soil particles. **B.** An epidermal cell with root-hair

(as is shown in Fig. 20 A), coming into close contact with the water surrounding each particle. This soil water, together with any soluble substances to which the protoplasm is permeable, will pass into the root-hair by osmosis and diffusion (cp. Chapter VIII). The rapid entrance of water dilutes the sap in the absorbing cells.

FIXING ACTION OF THE ROOT-HAIR. The root-hair is an excellent fixing organ as well as an organ of absorption. It adheres so closely to the soil particles that it is impossible to pull up a plant by its roots without destroying most of the root-hairs.

PASSAGE OF WATER THROUGH THE PLANT. What happens to the water absorbed by the root-hairs? The following experiments throw light on this question.

Experiment 27. To show that osmosis can take place through a compact mass of cells, peel two large potatoes, cut off one end of each so that it will stand upright, and scoop out the centre to make of the potato a rough basin. Place a little sugar solution in the bottom of one basin, leave the other empty, and stand both potatoes side by side with their lower ends in water. After a time examine them again. One is still dry, but the other, into which we put a little sugar solution, is now full of liquid. We learn that, given the necessary conditions, osmosis can take place through the whole tissue.

This is what occurs in the root. Inside the epidermis is a mass of thin-walled tissue, the cortex. The absorbed water gradually passes through this from the root-hair (*a*) into *b*, and so on until it has penetrated the whole cortex (cp. Fig. 21 B). The next experiment traces its further path.

Experiment 28. Immerse seedling plants with their roots dipping into water coloured with eosin. After from 24 to 48 hours, wash the roots in tap water and then cut a series of slices (transverse sections), beginning well down the roots and passing upwards into the stem. In the stem cut careful sections at the node. Examine these sections with a lens or microscope.

Exercise. Cut radial longitudinal sections (i.e. sections passing through the centre) of the root and stem, and compare their appearance with those of the transverse sections.

We find that the coloured liquid has been absorbed and has travelled right through the axis of the plant and out into the leaves. We see, further, that this current of water has passed through the axis in certain definite channels. These channels are grouped very near the centre of the root (cp. Fig. 21); in a stem they are arranged in an open circle nearer the periphery (cp. Fig. 2).

Experiment 29. Trace the path of the coloured liquid in other suitable material, e.g. a woody stem, such as privet; or a large bud, such as the Brussels sprout. In each case the cut end is immersed in a coloured solution; after a time the path of the liquid is observed by cutting the specimen both crossways and lengthways.

In woody stems an alternative method is sometimes useful. The soft external tissues may be scraped away and the harder conducting tissue, now coloured red, may be traced through the stem and out into the leaves.

In every case we find that the liquid passes through the plant axis along certain well-defined paths; further, that we can trace it out along the veins into the lamina of the leaf.

THE INTERNAL STRUCTURE OF THE ROOT.

Exercise. Thin slices are cut with a sharp razor across the root of one of the plants used in the previous experiments. These are immersed in a solution of aniline hydrochloride, and mounted in glycerine. Examination with a lens shows that there is a central core in which certain structures are stained yellow. These agree in position with the structures along which the coloured liquid passed (experiment 28). Outside this core (the vascular or conducting tissue) is softer tissue, the cortex, bounded internally by the endodermis with its peculiarly thickened cells (cp. Fig. 21B). Outside the cortex is the epidermis (sometimes called the piliferous layer) with its root-hairs.

Fig. 21 shows a section of root as seen under the microscope (cp. Fig. 2). Near the centre are alternating groups (bundles) of wood (or xylem) and bast (or phloem). The wood is the chief water-conducting tissue, while it is believed that manufactured food travels through the bast.

The cells of the xylem have walls strengthened by a substance called lignin. This has been deposited as an additional layer on the inside of the original cellulose cell-walls, and it is this substance which stains yellow with aniline hydrochloride. Such woody cells are usually long; many are now quite empty of protoplasm and, as already described (cp. p. 30), have become transformed, by absorption of their cross-walls, into long tubes called vessels (cp. Fig. 22). These vessels are the chief water-conducting elements of the plant. Among them are a number of thick-walled fibrous cells which serve as skeletal tissue, giving support to the whole structure.

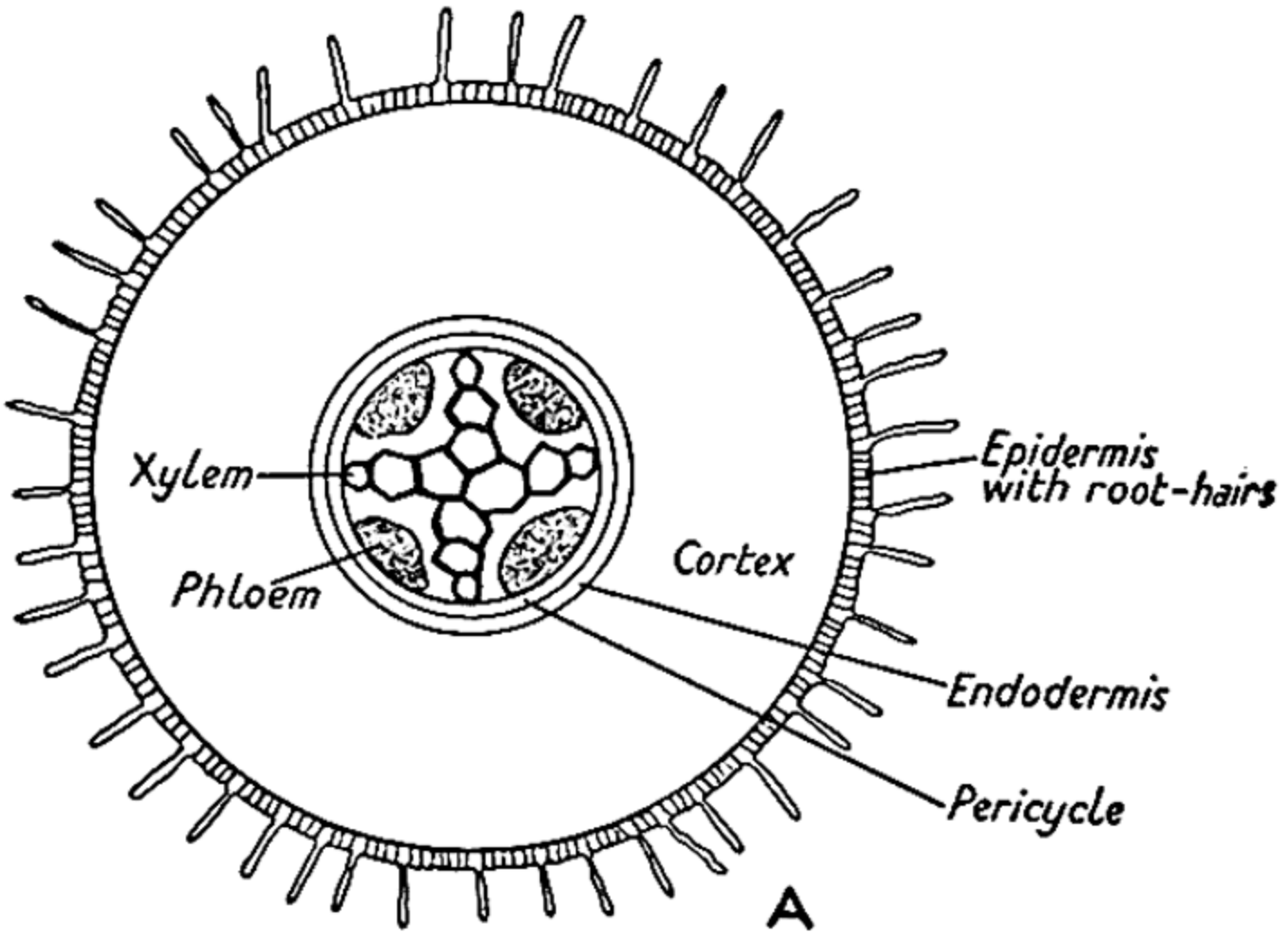


FIG. 21. A. Transverse section of a root to show arrangement of principal tissues. B. Portion of the above section more highly magnified

Exercise. Tease out the vascular bundles from the boiled petioles of celery or rhubarb leaves and examine the wood vessels under the microscope.

Phloem (bast) also contains elongated conducting elements; these are long thin-walled structures called sieve tubes, the cross-walls which separate the individual cells becoming pierced by many fine pores to form the 'sieves' (cp. Fig. 22).

Outside the conducting strands of the root we find the pericycle, from which branch roots arise, then the cortex, while the whole is bounded externally, in young roots, by the piliferous layer, with its root-hairs.

ENDOGENOUS ORIGIN OF LATERAL ROOTS.

Exercise. Cut a thin slice through any root at a point where a branch root is emerging. Examine and draw the section.

You will find that branch roots arise from the outermost layer of the central column (i.e. from the pericycle) of the main root and force their way through the cortex to the exterior. The end of every root is like a tentacle, helping to fix the plant and absorb soil water, and every lateral root brings its contribution to the stream of water flowing upwards into the stem.

THE INTERNAL STRUCTURE OF THE STEM.

Exercise. You are given some thin cross-sections of various stems (sunflower, dead nettle, broad bean, &c.). Immerse them in aniline hydrochloride solution as before, examine with a lens, and draw the sections.

In most flowering plants, when young, there are isolated strands or bundles running through the stem in the form of a hollow cylinder (a ring as seen in cross-section). These strands are grouped near the outside of the stem, leaving quite a large pith. Living cells, like those of the pith, separate the individual bundles and form the medullary rays. Outside the ring of vascular bundles is the cortex; its cells may be green, and hence they can assimilate. The whole structure is bounded by the colourless epidermis, with its thickened cuticle. In the young stem it usually bears stomates (cp. p. 103).

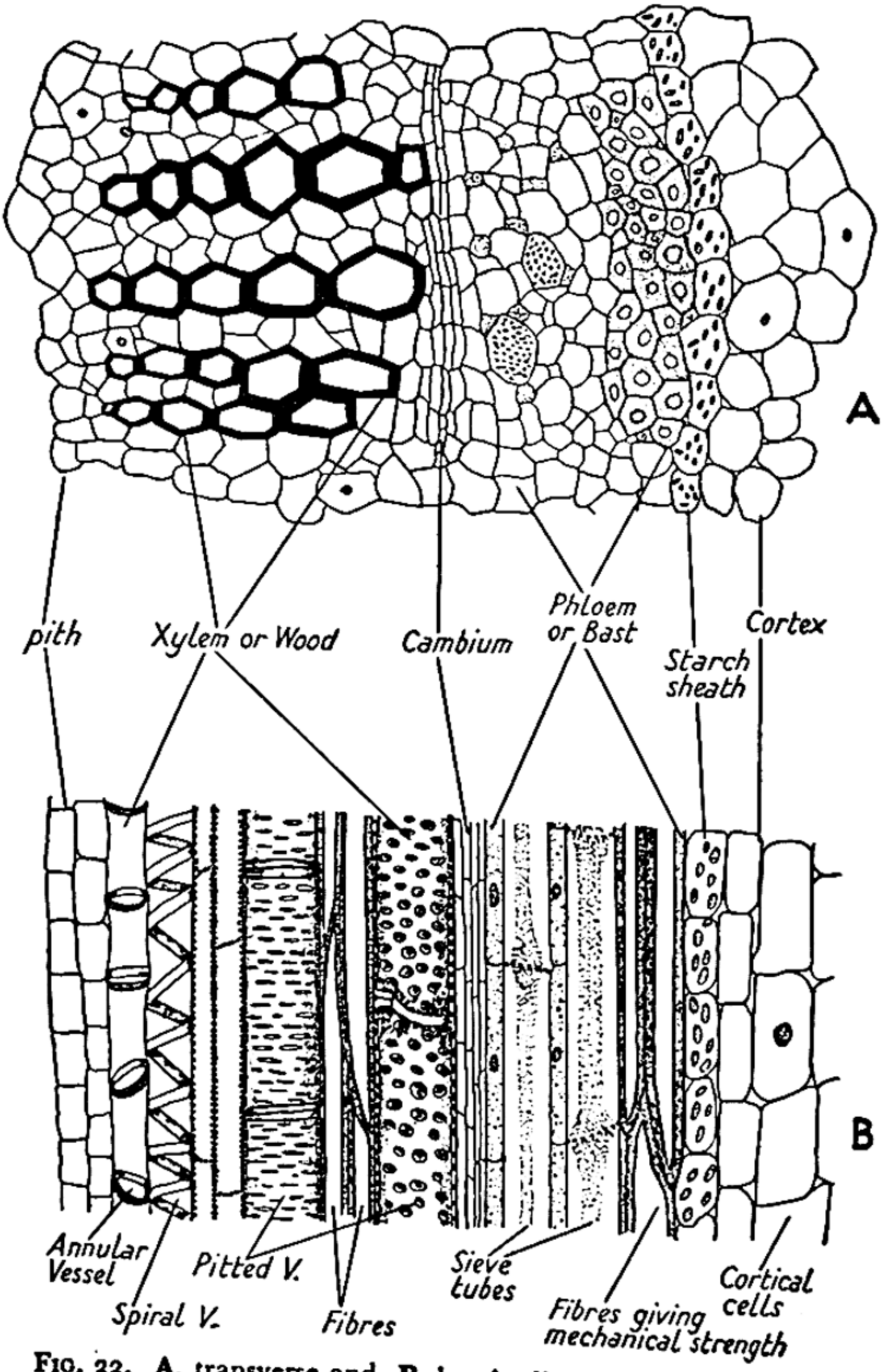


FIG. 22. **A**, transverse and, **B**, longitudinal sections of part of the stem of a flowering plant, to show the structure of a vascular bundle as seen under high power of microscope. (Diagrammatic)

THE VASCULAR BUNDLE OF THE STEM (cp. Fig. 2). This consists of wood (xylem) and bast (phloem) separated, in many cases, by the cells of the cambium (cp. Fig. 22). The wood and bast do not form alternating groups, as in the root, but are combined into one strand or bundle. The wood, like that of the root, consists chiefly of vessels, elongated cells, and supporting tissue, most of these elements having woody (lignified) walls. In the bast the most important structures are the sieve tubes.

The cambium, which is only visible in very delicate thin sections, consists of a single layer of thin-walled living cells, the only cells of the bundle which are still capable of growth (meristematic). We shall see (cp. p. 361) that they often play an important part in the later development of the stem.

Rigidity of the stem. The stem may contain mechanical tissue which helps to keep it rigid. Supporting tissue of this kind is very obvious in the stems of sunflower or dead nettle. It is often found quite apart from the bundles, in the cortex. A stem has to support its own weight and bear aloft its canopy of leaves; it also has to resist the strains set up by wind, snow, &c.; hence it needs skeletal tissue more than does the root.

We must, however, realize that the rigidity of a young stem does not depend ultimately upon any framework of mechanical tissue, but upon the rigidity (turgidity) of its individual cells. When water is plentiful the cell-walls are all taut, like the covers of so many inflated balloons. The walls are kept stretched by the presence of the contained water, just as a football or a bicycle tyre is rigid with compressed air. A plant tissue in which all the cells are turgid is quite rigid, without any other mechanical support.

Exercise. Leave some tender seedlings out of water for 24 hours or immerse them for an hour in strong salt solution. Observe the limp conditions of the stems after such treatment. We are all familiar with the miserable drooping condition of a room plant we have forgotten to water.

These exercises make it quite clear that the rigidity of the young stem depends on the turgidity of its individual cells.

A large amount of mechanical tissue is developed in older stems, especially in the woody branches of shrubs and trees; we shall return to this subject later (cp. Chapter XXVII).

To summarize what we have learned, *the axis of the land plant*, both root and shoot, is formed internally on the same general plan. The xylem of the root is continuous with that of the shoot, so is the phloem. At one end this conducting system begins in the young root branches (cp. Fig. 2), and it is continually added to as the plant grows. At the other end the system ends among the stem apices and the young leaves of the terminal and axillary buds, while, all along the stem, leaf veins pass out from it to end among the cells of the leaf (cp. Fig. 25). Suitably coloured water can be traced right through this system of conducting elements and out into the leaves.

ROOT PRESSURE. What keeps this current of water moving upwards through these very narrow channels? What part does the root play in this process? These questions are not easy to answer, and the forces which keep the water in motion are not entirely understood. But at certain seasons the roots seem to exercise a pushing force which helps to drive the water upwards. This force, known as root pressure, is not exhibited by all plants, nor does it exist at all times. It is particularly active in the spring.

Experiment 30. Take a potted fuchsia plant (or a healthy bean or geranium) and water it thoroughly. The next day cut off the main stem a few inches above the ground, and tie a bit of stout rubber tubing over the cut end. Fill the tubing with water and tie into its free end a long glass tube of fine bore (capillary tubing). Support this by tying it to a stick stuck in the earth. Watch the rise of water in the glass tube due to root pressure. In the course of a day or two it will often rise to the top and overflow.

Root pressure is not the only force which brings about this rise of water in plant stems (cp. pp. 111–12), but we must defer further consideration of this problem until we have discovered what happens to the water when it reaches the leaf.

Before we turn to this, our next investigation, it will be useful

to draw up a table of comparison between the structure of the typical root and of the typical stem, as they appear in a young herbaceous plant.

ROOT STRUCTURE AND SHOOT STRUCTURE. A SUMMARY AND COMPARISON.

Root	*Shoot*
1. A *descending* cylinder, its apex protected by a root cap.	1. An *ascending* cylinder, its apex protected by the terminal bud.
2. Usually *colourless*, never green.	2. Always *green*, at least in part.
3. The root branches (lateral roots) *repeat* the structure of the *main root*. The root is not divided into nodes and internodes.	3. Stems bear *leaves*; these are quite unlike the cylindrical *stems*. They occur in a definite order, and the stem is divided into *nodes* and *internodes*. Stems also produce branches like themselves. These begin as buds in the axils of the leaves.
4. Lateral roots are *endogenous* in origin.	4. Leaves and lateral stems are *exogenous* in origin.
5. Internally, the *conducting tissue* is concentrated *near the centre*.	5. The *conducting tissue* is nearer the *outside*, in the stem.
6. The strands of *wood and bast alternate* in the root.	6. The strands of *wood and bast* are *on the same radius* in the stem, each vascular bundle containing both wood (xylem) and bast (phloem).

QUESTIONS ON CHAPTER IX

1. Describe, with illustrative diagrams, the structure, both external and internal, of a young root, and show how this structure enables it to perform its functions.

2. What are root-hairs, where do they arise, and what are their functions? Describe two experiments that you have performed which throw light on these functions.

3. Describe the path of a water particle on its way from the soil into the leaf of a land plant. Describe any simple experiments you would perform to trace its path.

4. By means of labelled diagrams describe the structure of a young root and a young stem as seen in transverse section, and point out the chief differences between the two.

5. Describe, with the aid of diagrams, the external structure of (*a*) a young root, (*b*) a young shoot, and point out the chief differences between them.

6. Describe the structure of any seed and seedling plant which you have examined.

7. In what way is the general structure of *either* (*a*) a root-system, *or* (*b*) a leaf, fitted for the functions it has to perform? (Ox. & C.)

8. Describe by means of a series of labelled drawings the stages in germination of *one* named seed. (C.L.)

9. Describe the structure of a stem of a typical flowering plant. What are the functions of the different parts? (L.G.S.)

10. Describe the general structure of the root system of a typical flowering plant, and explain the functions of the various parts. (L.G.S.)

11. Write a careful description of a broad-bean seed and of its mode of germination. (L.G.S.)

12. Describe in detail (*a*) the structure and (*b*) the process of germination of a bean seed. (Ox.L.)

13. How do roots differ from shoots in their general structure and functions? Illustrate your answer by reference to the roots and shoots of a named herbaceous plant and a named tree; make explanatory sketches. (C.L.)

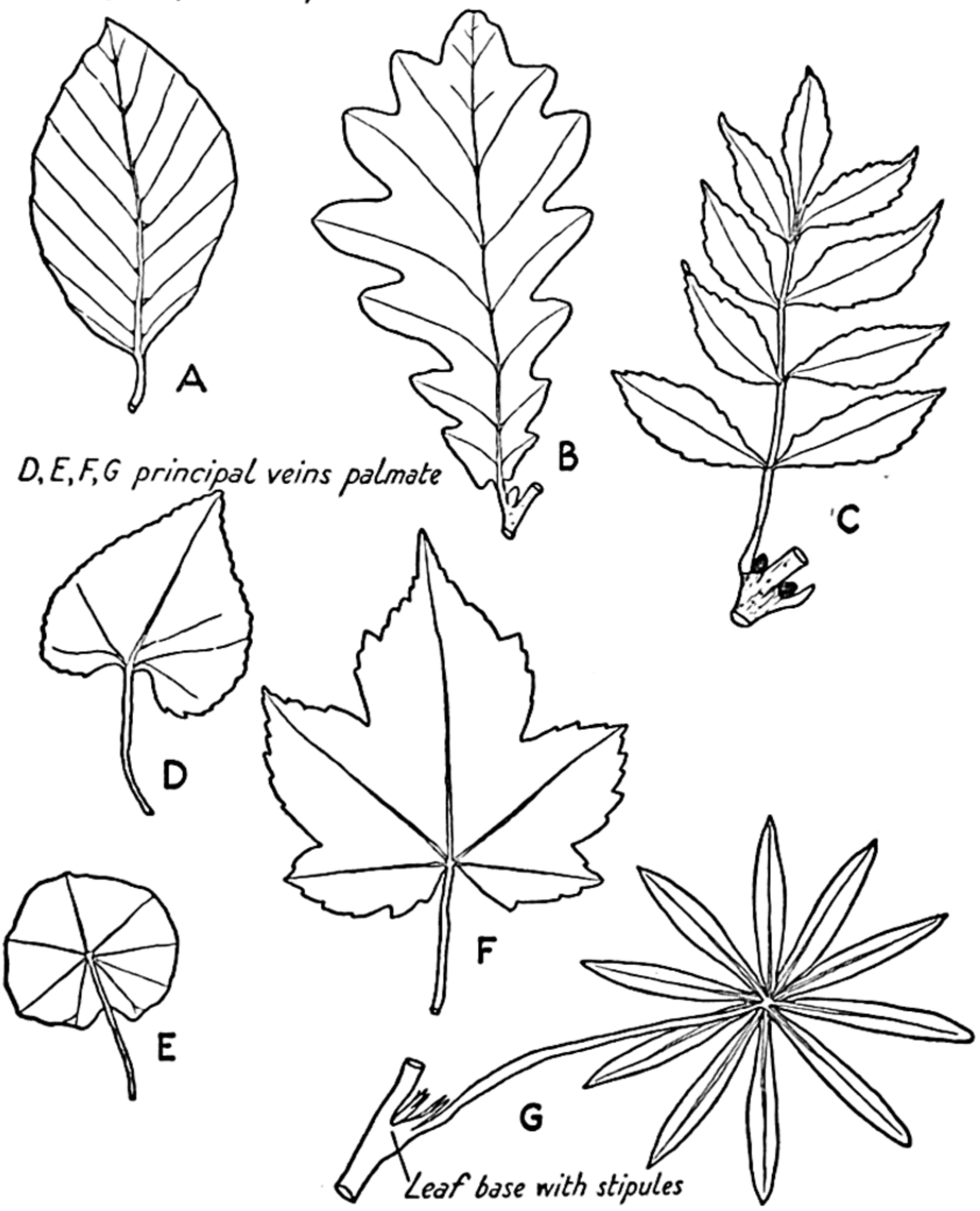


FIG. 23. VARIATIONS IN THE FORMS OF LEAVES. **A.** Simple leaf of beech. **B.** Lobed leaf of oak. **C.** Compound leaf of ash. **D.** Simple leaf of violet. **E.** Simple leaf of nasturtium. **F.** Lobed leaf of sycamore. **G.** Compound leaf of lupin. (All reduced)

CHAPTER X

THE LEAF, ITS STRUCTURE AND FUNCTIONS

We have traced the passage of a current of water from the root-hairs, where the water enters, across the cortex, into the water-conducting elements (xylem) of the root and stem, and out into the leaf veins. What happens to it then? This question can only be answered after a more detailed study of leaf structure.

THE EXTERNAL STRUCTURE OF A TYPICAL LEAF. Leaves, which are the chief assimilating organs of the flowering plant, are formed as outgrowths of stems, originating near the stem apex (cp. Fig. 2). They always arise in some definite order; alternately, in crossed pairs, or spirally. The typical leaf is a broad, thin, flat organ in which the surface is very large as compared with the volume. It does not grow indefinitely, as does the stem, but soon attains its full size. It is usually short-lived, lasting for one season only; the leaves of evergreens, however, may live for several years.

Exercise. Examine a privet leaf, or broad-bean leaf, and confirm the following facts.

A typical foliage leaf consists of three parts:

1. The blade or *lamina.*
2. The stalk or *petiole.*
3. The *leaf base*, which often bears a pair of outgrowths called *stipules.* These are well seen in the leaves of rose, broad bean, pea, &c.

The leaf base attaches the leaf firmly to the stem and shelters the young axillary bud. The petiole carries the lamina, which is the assimilating portion of the leaf, out away from the stem, so that it is exposed to light and air. This lamina is penetrated in every direction by veins.

Exercise. Examine and draw the leaves of grasses, ivy, privet, oak, rose, lupin, sycamore, &c., carefully observing the shape of the lamina and the arrangement of the principal veins.

PARALLEL- AND NET-VEINED LEAVES. Some leaves are parallel-veined, as in grasses, bluebells, and daffodils. This arrangement

of the veins is characteristic of *Monocotyledons*, one group of flowering plants, while in nearly all *Dicotyledons*, the other and larger group, the leaves are net-veined. We shall discover other differences between these two classes of flowering plants in subsequent chapters (cp. p. 347).

In net-veined leaves the principal veins may all spread out at the top of the petiole (geranium, ivy, sycamore); such an arrangement is called *palmate*. In others there is one central vein or midrib, from which the branch veins arise (privet, oak, rose). This venation is called *pinnate* (cp. Fig. 23).

SIMPLE, LOBED, AND COMPOUND LEAVES. The lamina of the leaf is very varied in form. Usually long and narrow in parallel-veined leaves, in the broader net-veined type it may be simple and undivided (box, privet); indented or lobed, as in ivy and oak; or divided up into separate leaflets, forming a compound leaf (lupin, rose). In lobed and compound leaves the arrangement of the subdivisions follows that of the principal veins (cp. Fig. 23).

The margin of the leaf varies also; it may be smooth (entire), toothed, or lobed in a characteristic way. The surface, too, differs in different leaves; some are smooth, others hairy, others waxy, and so on. Most of these features are illustrated by the leaves mentioned in the previous exercise.

STRUCTURE OF THE PETIOLE. Externally the petiole looks something like a stem. It may be long, short, or completely absent, when the leaf is called sessile. It is, however, only rounded on its lower surface, being usually flattened above, so that its cross-section is different from that of a stem. Moreover, it does not contain a ring of bundles (cp. p. 94). Often there is a single bundle passing through the petiole; in other cases, especially in leaves with palmate veining, the petiole may contain a small group of bundles arranged in an open arc. These bundles are on their way out from the conducting cylinder of the stem into the lamina of the leaf.

INTERNAL STRUCTURE OF THE LAMINA. The leaf lamina consists of a central mass of green cells, known collectively as the *mesophyll*, among which the veins end, and a thin protective covering, usually only one cell thick, known as the upper and

lower *epidermis*. It is easy to confirm these statements by simple experiments.

Exercise. Strip off a fragment of the outer layer of cells (epidermis) of an iris leaf. It comes away as a thin transparent sheet. This

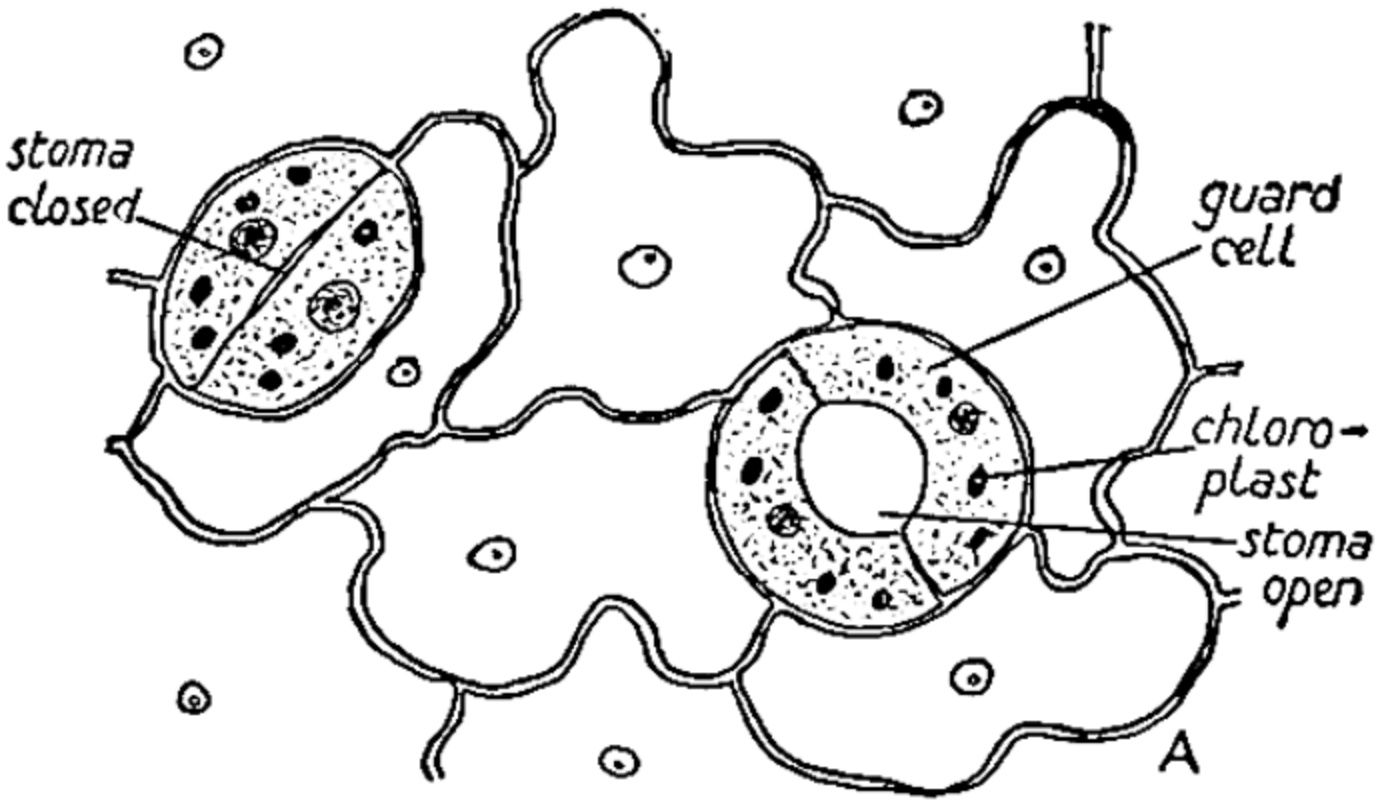


FIG. 24. **A.** Portion of leaf epidermis with stomata in surface view. **B.** Section of epidermis and stomate. (Both highly magnified)

epidermis is one cell thick, and colourless, as in most leaves. Mount a fragment in water, and set aside for examination.

Exercise. Boil some box or privet leaves in a solution of caustic potash for 5 or 10 minutes. Place in clean water, and cut off the margins of some of the leaves with scissors. Gently tease apart the remainder of the leaf; it can often be separated into three layers. Fragments of each layer should be mounted, and examined with a lens or under a microscope.

Examine first of all the two almost colourless outer layers. One, the upper epidermis, consists of small cells of irregular shape which fit closely together like a mosaic. The lower epidermis is similar, but among cells like those described are definite minute pores, called stomates. Surrounding each pore are two kidney-shaped cells, the guard cells (cp. Fig. 24). Their function is to alter the size of the stomate.

Examine now the epidermis of the iris leaf. The epidermal cells, which are larger than in the box, are long, colourless, and close-fitting (cp. the onion cells examined previously, p. 24).

The stomatal apparatus is large and clear. (Draw a stomate.) The guard cells are rich in protoplasm and, unlike the other cells of the epidermis, are green, containing chloroplasts. In them the nuclei can usually be seen.

THE ARRANGEMENT OF THE STOMATES. In some leaves, especially the long, narrow ones characteristic of monocotyledons, the stomates are distributed equally over the whole surface of the leaf. In others their distribution is by no means so uniform. This is especially the case in leaves with a definite upper and lower surface (dorsiventral leaves). In most of these the stomates are confined to the lower surface (box, privet), or are more numerous there (cherry, laurel). There is, however, no universal rule. In the leaf of the common white clover, for example, there are on the average 163 stomates per square inch on the upper face and only 106 on the lower. In the water-lily stomates are found on the upper surface only, there being about 11,000,000, it has been estimated, on any one leaf. In spite of such exceptions it is true that, in the majority of dorsiventral leaves, the stomates are more numerous in, or entirely confined to, the lower epidermis.

THE MESOPHYLL AND VEINS.

Exercise. Examine the mesophyll of the box or privet leaf (continuing exercise p. 103) and observe the course of the veins. They branch and branch, and finally end blindly among the mesophyll cells. Draw one of these free endings; as many as 6,000 minute veins may end in 1 sq. cm. of mesophyll.

Exercise. Examine a prepared cross-section of a leaf, and compare with the structure shown in Fig. 25. Notice the colourless epidermis with its cuticle, the mesophyll cells arranged as a palisade

mesophyll near the upper surface, and the spongy mesophyll towards the lower surface. In this part of the leaf the cells are irregularly arranged, enclosing large air-spaces.

Exercise. Plunge some fresh green leaves quickly into boiling water and observe the air which escapes through the stomates.

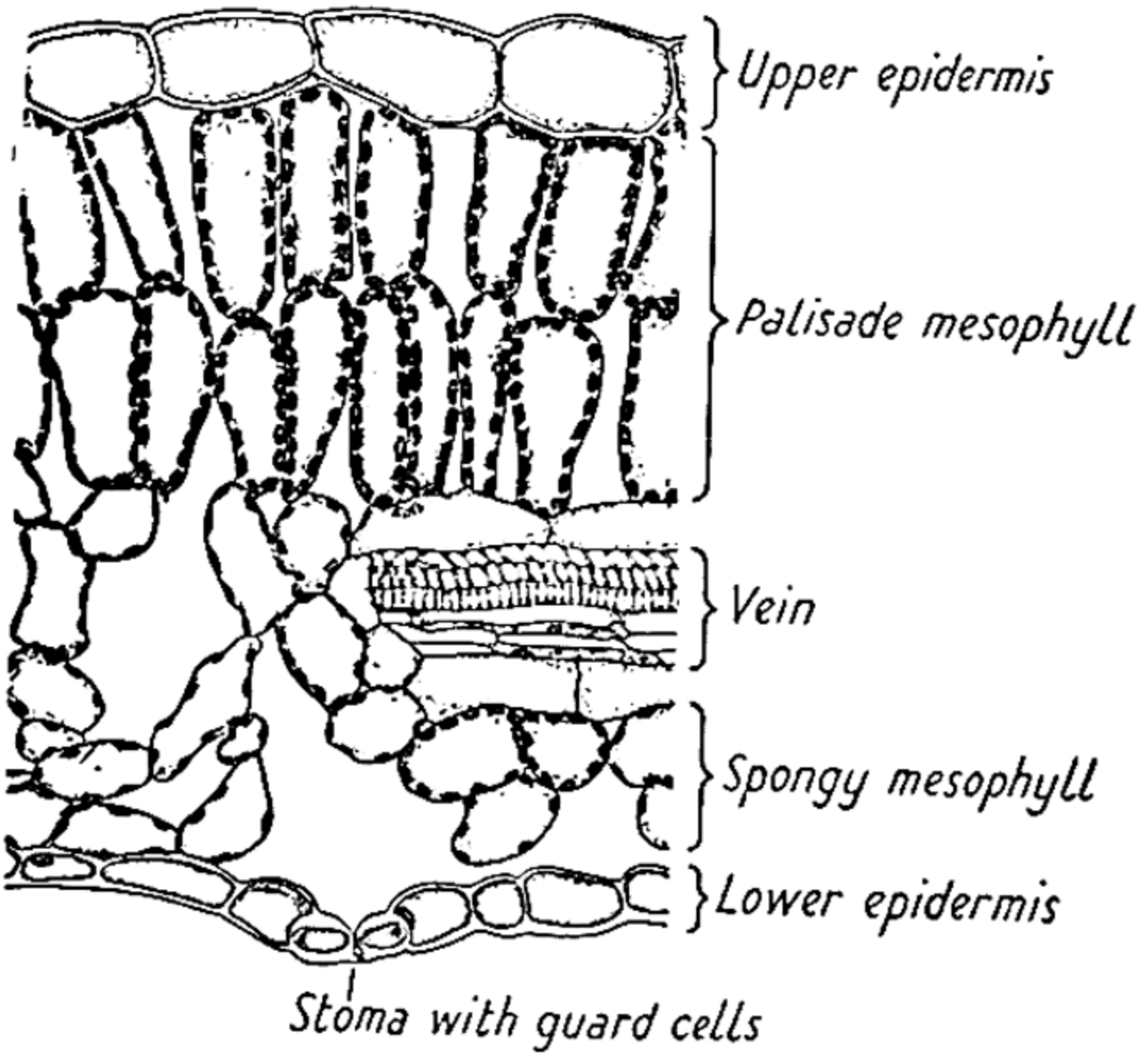


FIG. 25. A small portion of the cross-section of a typical green leaf, as seen under the microscope. (Highly magnified)

THE GREEN LEAF, AN ORGAN FOR PHOTOSYNTHESIS. The whole structure of the leaf fits it admirably for its work of photosynthesis. By its position, hung out like a flag on the stem which produced it, it is freely exposed to the light and air. Thus the green cells are so placed that each receives the light it requires. Every cell of the mesophyll must obtain light directly for its work of assimilation.

Every green cell must also be provided with the necessary raw materials, and the structure of the leaf is such that these have free access to the assimilating cells. Stomates allow carbon dioxide to diffuse freely into the air-spaces of the leaf;

veins bring up water absorbed from the soil. This water saturates the walls of the mesophyll cells; carbon dioxide becomes dissolved in it, and both the water and the dissolved gas pass freely through the wet cell-walls into the green cells, where they can be used for photosynthesis. It is in these mesophyll cells that the manufacture of the world's food is begun.

Its very excellence as an organ for assimilation makes the leaf less efficient from another point of view. Gases must be able to enter it freely (since carbon dioxide is essential), and they do so through the stomates. Inside the leaf air is thus in direct contact with the wet cell-walls. If it is unsaturated some of the water will evaporate; the vapour collects in the internal air-spaces and gradually diffuses out at the stomates (cp. p. 77); more air enters, and more evaporation occurs. Hence we find that the leaf, in spite of the protective cuticle (cp. Fig. 24), is not a good conserver of water—a fact which may be fraught with danger for the plant living on land. Let us now study this loss of water from the leaf surface in greater detail.

THE LOSS OF WATER FROM THE LEAF. TRANSPIRATION.

Experiment 31. Water a pot plant and cover pot and soil with mackintosh sheeting to prevent loss of water from these exposed surfaces. Place the pot on a glass plate and cover it with a dry bell jar. A similar apparatus, without a plant, is set up as a control. Water soon collects on the sides of the bell jar covering the plant; the other jar remains dry. The plant is giving off water vapour, and this vapour condenses on the cool sides of the jar. How much water is given off in this way?

Experiment 32. To examine the relation between the water absorbed and the water lost by transpiration fill a small measuring-jar with water, and place in it a leafy shoot with its end dipping into the water. Cover the surface with oil to prevent direct evaporation. Read the level of the water and weigh the whole apparatus every 24 hours for about a week. The level of the water falls: this is due to absorption by the plant. The apparatus also loses weight, and furthermore the total weight lost is roughly equal to the weight of water absorbed. Thus, in one experiment, 10·3 c.c. of water were absorbed; this water would weigh, roughly, 10·3 gm. The apparatus lost 9·8 gm. in weight; this loss is obviously due to loss of water

vapour. Hence, of 10·3 c.c. of water absorbed in this experiment, only 0·5 c.c. was retained for the use of the plant.

Experiment 33. As a check on the previous experiment, to ascertain the exact weight of water given off by a plant we may repeat experiment 31, covering the whole apparatus with a bell jar under which is a dish containing a weighed amount of calcium chloride. Calcium chloride absorbs water vapour, and at the end of the experiment its weight has increased by just the amount which the plant has lost.

TRANSPIRATION A SECOND FUNCTION OF THE LEAF. This process of giving off water vapour is called transpiration. The amount of water lost is very striking; it has been estimated that, in one season, an acre of maize requires 4½ tons of water for photosynthesis, but loses 1,700 tons by transpiration. From one point of view, each plant is a living pump, removing water from the soil and giving it back as vapour to the air. For each gramme of starch formed a sunflower plant will not only rid the air of 2 cubic metres of carbon dioxide, but will absorb 250–400 c.c. of water, so that each plant absorbs nearly 700,000 c.c. (i.e. about 150 lb.) of water in one growing season. Now mosquitoes carry malaria (cp. p. 313), and they breed in stagnant water; we understand why the Romans found it useful to plant sunflowers on the Campagna to keep down malaria. Experience led them to do blindly what modern science has been able to justify.

Why do plants lose all this water? It may be simply because the loss cannot be prevented. The leaf is primarily an organ for photosynthesis and its whole structure, as we have seen, fits it for this purpose. The mesophyll (cp. Fig. 25) is permeated by air-spaces; its cell-walls are wet.

The conditions inside the leaf resemble those found in the drying-room of a laundry, where all the windows are open and gaseous diffusion goes on unhindered. Water evaporates from the wet clothes, and the moisture drifts out at the open windows.

In the leaf the water evaporates from the wet cell-walls and diffuses out as vapour through the stomates. The structure of the leaf makes this loss unavoidable.

INFLUENCE OF STOMATES ON TRANSPIRATION.

Experiment 34. Take two dry dusters, place on each a geranium or privet leaf, one with the upper and the other with the under surface uppermost. Across the middle of each leaf place a strip of dry cobalt chloride paper. Cover each with a glass plate. The blue cobalt paper gradually turns pink. It is absorbing water vapour. The change occurs much more rapidly in the paper covering the lower epidermis, for the vapour escapes chiefly through the stomates.

CLOSING OF STOMATES. It is known that stomates, which are primarily organs for the entry of carbon dioxide, partially close at night, this closure being dependent upon the fact that they are green, while the other epidermal cells are colourless. Does this closure influence the rate of transpiration? The following experiment will show that it does.

Experiment 35. Repeat experiment 31, omitting the bell jar and simply weighing the potted plant night and morning for a week. We can thus find the total loss due to transpiration.

We find as a rule that the loss during the hours of daylight far exceeds that during the night. The partial closure of the stomates is one of the factors tending to decrease transpiration.

INFLUENCE OF EXTERNAL CONDITIONS ON TRANSPIRATION. Transpiration being a form of evaporation, though partly controlled by the structure of the leaf, we should expect that it would vary with external conditions, and it is easy to show by experiment that it actually does so.

Experiment 36. Continue experiment 35 for some weeks, re-watering the pot occasionally. Record the temperature, the humidity of the air (from readings of the wet and dry bulb thermometer), whether the day is sunny or overcast, rainy or dry, &c. If the external conditions are carefully recorded and compared with the amount of water lost by transpiration from day to day, we soon find that this process is very dependent on external conditions.

Experiment 37. We may investigate the influence of external conditions on the rate of transpiration by means of a potometer. This is an apparatus which enables us to compare the rate of absorption of a cut leafy shoot under different external conditions, the rate of absorption being about equal to the rate of transpiration.

One form of this apparatus is shown in Fig. 26. It consists of a glass

tube of the shape shown. Three well-fitting rubber stoppers are chosen, which can be inserted in the tube at *A*, *B*, and *C*, those for *B* and *C* each being pierced by a hole. The hole in *B* admits a length of glass capillary tubing, that in *C* the stem of the twig that is being investigated.

To use the apparatus we fill the potometer tube under water, and push in the stoppers at *A* and *C*, keeping it submerged until the cut end of the stem has been pushed through the stopper *C*.

The stem used for the experiment (e.g. privet) should be cut off under water, and then kept with its cut end in water for some hours. Just before inserting it in the stopper *C* a further short length is cut off by means of a sharp razor; this cut must be made under water. We make sure that there is a good joint between the stopper and the stem, wiring this joint if necessary.

The potometer tube is now inverted and raised, so that the end *B* points upwards; the stopper bearing the capillary tube is pushed into position at *B* (a fine spray of water will escape at the end of this tube). Finally the apparatus is again inverted and supported by a retort stand and clamps, with the end of the capillary tube dipping into a beaker of water.

To take a reading we must raise the potometer slightly and suck a little water out from the end of the capillary tube by applying blotting-paper to that end; in this way we create a small air-bubble. The tube is now put back into position with its end dipping into water. Two marks have been

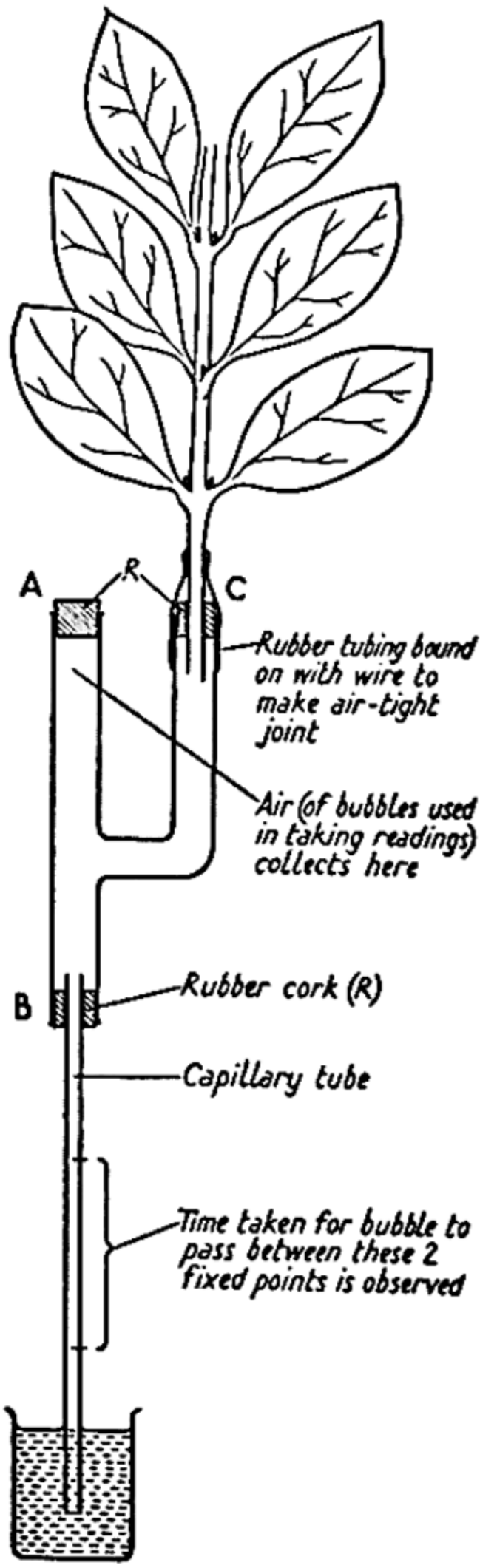


FIG. 26. Potometer to compare rates of absorption (and hence of transpiration) of a cut leafy shoot under different external conditions

made on the tube a few inches apart. We observe the time taken for the bubble to pass between these marks, using a stop watch.

Take several readings, making a fresh bubble for each observation.

Now change the external conditions. You may, for example, (1) create a current of air by vigorous fanning; (2) create a dry atmosphere. To do this, cover the twig, &c., with a bell jar, and close the bottom of the jar by a sheet of stout cardboard cut so as to slip sideways round the stem; now put some anhydrous calcium chloride under the jar to absorb moisture. After waiting a short time for the plant to adjust itself to the new conditions, take another set of readings of the time taken for bubbles to pass between the two fixed marks. (3) Try the effect of transferring the whole apparatus to a dark room, taking care that the conditions of temperature, humidity, &c., remain unchanged. Again allow a short time to elapse before you begin observations. Time the bubble with the aid of a torch so placed that its light does not fall on the twig.

A comparison of these various readings shows clearly that external conditions affect the rate of transpiration.

FACTORS THAT INFLUENCE THE RATE OF TRANSPIRATION.

I. *External factors.* Since transpiration depends on evaporation, everything that increases evaporation will increase transpiration. High winds, dry air, high temperature, all make for rapid transpiration, while still, moist air and a low temperature all decrease it.

II. *Internal factors. Xerophilous leaf structure.* The amount of water lost by a plant depends very largely on the structure of its leaves. The fewer the stomates, the less the loss, if other factors are equal. Small-leaved plants lose less than those with large leaves; hence such plants (e.g. heather, pine-trees, gorse, &c.) can often survive on ground where their large-leaved competitors perish for want of water. We cannot enter here into all the variations of leaf structure shown by plants that live where water is scarce. The student is advised to study the plants of a sandy shore or a sandy common, of an alpine rockery, or of some semi-desert in the nearest botanic gardens. He will observe that all such plants exhibit some of the following features:

(*a*) Very small leaves—or leaves entirely absent (e.g. gorse, broom).

(*b*) Waxy or hairy covering to the epidermis (e.g. sea holly, &c.).

(*c*) Protection of the stomates—they are sunk below the general level of the epidermis, or the leaf is rolled so that they open into a partly closed cavity, &c. (e.g. pine leaves; Psamma).

(*d*) The leaves may not only be small, but also thick and fleshy, storing water in their fleshy tissue against times of drought (e.g. stonecrop, houseleek).

All these features tend to economize water; plants with such leaves are called *xerophytes* (cp. p. 124).

THE USES OF TRANSPIRATION. Transpiration is the giving off of water vapour from the leaves of land plants. Although, as we have seen, this process is probably to be regarded as a somewhat dangerous one, impressed on the land plant by its structure, nevertheless it has certain useful functions. Unlike animals, plants do not possess hearts, which, by their contraction, keep the blood in circulation; yet water is raised to great heights in tall trees, and this in spite of the fact that it passes through very narrow vessels in which one would expect the resistance to be high.

(1) This *raising of water* is one of the chief consequences of transpiration, evaporation from the leaf surface causing more water to be sucked up by the mesophyll cells and so giving rise to a movement of the whole water-content of the plant. The water in the wood vessel seems to move like a solid rod which it is difficult to break. As some escapes by evaporation from the end of the column, the whole column rises, and more water is therefore absorbed by the root-hairs.

(2) This movement of water brings with it a *movement of the salts* required for food-making.

(3) Evaporation always causes cooling, and it has been suggested that transpiration *prevents leaves from becoming overheated.* Every one has noticed how much hotter is bare sand or rock than the same substance covered with vegetation.

LIFTING FORCE DUE TO EVAPORATION. To illustrate the fact

that, when water is evaporated, it can exert a 'pull' which will raise more water from below, we may set up the following experiments:

Experiment 38. Take some fine clay (or plaster of Paris), make it into a wet 'dough', and fill it into the top of a thistle funnel, thus closing the mouth of the tube. When it has set fill the tube with previously boiled water (the water is boiled to expel air), close the narrow end with the finger, and invert the apparatus, dipping this end into a beaker of coloured water. This water is gradually drawn up the tube and in time the clay itself may become coloured.

Experiment 39. To show that a leafy shoot can suck up water choose a branch of willow or maple on which the young leaves are fully expanded, cutting it off under water. Attach it by means of a piece of stout rubber tubing (4 or 5 cm. long) to a glass tube about 50 cm. long. Both rubber tube and glass tube must previously be filled with water. Tie the rubber firmly both to the twig and to the glass. Now, holding a finger over the end of the glass tube, raise the whole apparatus into the vertical position; dip the end of the tube into a small beaker of mercury. As water is absorbed by the twig the mercury begins to rise up the tube.

We gather that transpiration is largely responsible for the drawing up of water through the plant (cp. p. 97), and may now summarize the many important functions of the leaf.

THE FUNCTIONS OF THE LEAF. A SUMMARY.

1. The leaf is primarily an organ for *photosynthesis*—making sugar and starch. Its whole structure fits it for this work.
2. If more food is made than is immediately required the surplus is stored in the leaf cells, usually as starch. This *storage* only occurs in daylight.
3. The starch is digested and passed on to the other organs of the plant after sundown (*translocation*).
4. *Transpiration* takes place from the surface of the leaf. This helps to keep the stream of water moving through the plant, and may also be useful in preventing the overheating of the leaf cells in hot weather.
5. The leaf cells, like all living cells, *respire* (cp. Chap. XXI).
6. The leaf is possibly the chief seat of *other food-making activities*, e.g. of the synthesis of proteins.

QUESTIONS ON CHAPTER X

1. Describe the structure, both internal and external, of a foliage leaf.

2. Make accurate drawings illustrating the external structure of the following leaves: clover, rose, blackberry, ivy, vetch, sweet pea, clematis. Comment on any interesting features which they exhibit.

3. Describe the structure of a typical foliage leaf, and show how that structure fits it to perform its functions.

4. The leaf is sometimes described as 'the principal factory of the world'; justify this statement.

5. What do you know of the processes going on in a green leaf (*a*) by day, (*b*) after sunset? Describe any two experiments you have performed which support your statement.

6. What is transpiration, and what is its use to the plant? Describe how you would measure the rate of transpiration of a potted plant (*a*) by day, and (*b*) by night. What difference would you expect to find between the two measurements; give reasons for your answer. (L.G.S.)

7. Make a list of all the features which are common to all or nearly all green leaves, and explain, as far as you can, the use of these features to the plant.

8. How would you distinguish between (*a*) a stem bearing leaves, and (*b*) a compound leaf with its leaflets? Illustrate your answer by sketches, giving the names of the plants drawn.

9. Describe two experiments by which you could demonstrate that leaves give off water vapour. How do external conditions affect this process? Account for their influence as fully as you can. (L.G.S.)

10. Draw (1) an aerial, and (2) a submerged leaf of the water buttercup. What are the chief differences between the two? Account for these differences as fully as you can.

11. Describe the structure and the arrangement of the veins in a typical foliage leaf. What are the functions of these veins? Describe one experiment which supports your statements.

12. Describe carefully experiments you have carried out on the green plant, illustrating its function in relation to (*a*) transpiration, and (*b*) nutrition. (C.W.B.)

13. What is transpiration, and why must plants transpire? How could you demonstrate the path of the water current through a plant? (L.G.S.)

14. How could you measure the amount of water (*a*) taken in, (*b*) given out by a green plant during a given period of time? (Ox.L.)

15. Describe the structure of a typical foliage leaf and the functions which it performs. (L.G.S.)

16. What is transpiration, and how is it performed in a green herbaceous plant? A potted plant which is wilting may be revived by watering the soil, or often by simply spraying water around the plant with a fine syringe. Explain what happens in each case. (J.M.B.)

17. How would you demonstrate that a green plant is transpiring? How do atmospheric conditions influence the rate of transpiration? (J.M.B.)

18. In what way is the general structure of a leaf fitted for the functions which it has to perform? (Ox. & C.)

19. What are the veins of leaves? Describe their appearance in three named plants as seen from the upper and lower sides. What experiments could you suggest which would throw any light on the functions of the veins. (Ox. & C.)

20. Describe the form and arrangement of leaves in a green herbaceous plant which you have studied. What are the veins of a leaf and what are their uses? (J.M.B.)

21. When rose leaves are placed under hot water, bubbles of air are seen all over the under surface of the leaves, but there are none on the upper surface. Explain the meaning of this observation and describe any two experiments which throw light on this phenomenon.

22. What are the functions of the transpiration current? How is the plant adapted to allow the passage of water, and how is the flow of the current controlled? (Ox.L.)

23. What is meant by transpiration? How would you proceed to demonstrate that a cut shoot of a rose transpires? (Ox. & C.)

24. Of what importance is water to a green plant? Describe an experiment by which you could determine the rate at which water *either* entered *or* left a leafy shoot. Draw the apparatus you would use. (C.L.)

25. How would you find out the weight of water transpired by a plant in a pot in a given time? How would you proceed to find the weight transpired per sq. centimetre of leaf in 1 hour? (Ox. & C.)

SOME SUGGESTIONS FOR FURTHER READING

CHAPTERS V–X

General readers.

The Green Leaf. Macdougal. (Appleton.)
Plants. Seward. (C.U.P.)
What Botany Really Means. Small. (George Allen.)
The Romance of Plant Life. Selous. (Seeley Service.)
The Life of Plants. Sir F. Keeble. (O.U.P.)
How You Work. Isabel Wilson. (Gerald Howe.)
Food, Health, Vitamins. Plummer. (Longmans, Green & Co.)

Text-books.

Easy Experiments with Plants. H. McKay. (O.U.P.)
School Botany. Macgregor Skene. (O.U.P.)
Botany. A Junior Book for Schools. R. H. Yapp. (C.U.P.)
The Elements of Botany. R. J. Harvey-Gibson. (Nelson.)
Experimental Biology. Smith. (O.U.P.)

CHAPTER XI

THE SOIL AND ITS INFLUENCE ON VEGETATION
SOIL BACTERIA

SOIL. We have seen how the green land plant obtains its raw materials, and we know something about the processes by which it elaborates them into food. We turn now to study the soil in which these plants are rooted and from which they withdraw both water and the mineral salts they require.

The earth's crust is formed of rock—clay, sandstone, limestone, &c. This rock becomes slowly broken up by weathering agents such as rain and frost, and forms the *subsoil*. The subsoil is further disintegrated by similar agencies, as well as by the living creatures (e.g. plant roots, earthworms, &c.) which burrow into it; it becomes mixed with the decaying remains of dead plants and animals, and this mixture of minute rock particles and *humus* (decaying organic matter) forms the *top soil* from which plants draw their raw materials.

SEDENTARY AND TRANSPORTED SOILS. Sometimes the top soil has been formed where it is found; very often, however, rock particles are carried off to be deposited again, perhaps hundreds of miles from their place of origin; the alluvial soils of river deltas, the glacial-drift soils which were deposited in the far-off ice ages, are examples of these transported soils. The sea is another great weathering and transporting agent; certain pebbles picked up on the east coast of England have probably come from Norway, for example, as no rocks of stone similar to these pebbles can be found nearer.

EXPERIMENTAL EXAMINATION OF THE SOIL. The soil provides the water and mineral salts which plants require. It must be so loose that the roots can penetrate it, and yet so firm that the same root can obtain a good hold and keep the plant, even if it be a tall and top-heavy tree, firmly fixed in the ground. It must contain the necessary air and water, also all the salts which the plant needs. It is the first concern of every plant-grower to keep his soil in good condition, &c , and to make

good any deficiency in the necessary salts by suitable manuring.

Let us now examine some garden soil, and see what we can learn about its properties.

Exercise. Spread out some dry garden soil on white paper and examine it with a lens. Notice the size and shape of the rock particles; also the fragments of blackish humus.

THE SIZE OF THE SOIL PARTICLES. A MECHANICAL ANALYSIS.

Experiment 40. Put some soil into a tall gas-jar. Mix to a paste with water, rubbing out all the lumps. Fill up the jar with water and stir well. Cover the open end with a glass plate and shake thoroughly. Now leave the jar to stand undisturbed for some days.

The soil settles in layers at the bottom of the jar. Small stones and coarse sandy particles are the first to fall, then particles of progressively smaller size, the smallest being the last to settle. The very finest remain suspended in the water. Some humus is found on top of the soil layers, some is floating on the water. This experiment separates the soil into particles of different sizes and enables us to estimate the proportions of the various sizes in the soil.

AIR CONTENT OF SOIL.

Experiment 41. To show that soil contains air put some earth in the bottom of a measuring-cylinder and leave it to settle thoroughly. Read the volume of the soil and pour on it an equal volume of water. Air bubbles are seen to escape as the water gradually penetrates among the soil particles. The final volume of soil and water is much less than the volume of the soil added to that of the water. The difference obviously gives the amount of air that was trapped among the soil particles.

WATER CONTENT OF THE SOIL.

Experiment 42. The water content is obtained by first weighing a sample of soil, then drying it at 100° C. until its weight is constant. The difference between the initial and final weights tells us the amount of water in the sample. By repeated experiments of this kind the average water content for the year can be estimated.

HUMUS CONTENT OF THE SOIL.

Experiment 43. To discover the percentage of humus inthe soil take the dry soil left from experiment 42 and heat it strongly. The

humus burns away, the soil becomes lighter in colour. Continue until the weight is constant. The loss during burning gives the weight of humus present.

The above experiments show that the soil consists of rock particles and humus, and contains air and water. Soils chiefly differ in:

1. The nature of the rock from which they are formed.
2. The size of the component particles.
3. The amount of humus, air, and soluble materials which they contain.

All these varying features exert a profound influence on the plants which grow in the soil, different soils having different properties. Let us look at some of the more important of these.

SIZE OF SOIL PARTICLES. Many important properties of the soil depend upon the size of the constituent particles. In well-drained soils water adheres to each particle as a surface film, while air fills the spaces between (cp. Fig. 20). A number of small particles will hold more water in this way than one large one occupying the same space. For example, a cube of 10 cm. edge has a surface of 600 sq. cm. If the cube is subdivided into 1,000 smaller cubes of 1 cm. edge, the volume is unaltered, but the exposed surface is now 6,000 sq. cm., i.e. it has increased tenfold. The smaller cubes would, if dipped into water, hold ten times as much water on the surface as the one larger cube. For this reason a fine-grained soil, such as a clay soil, has a large water content and is often wet; a coarse sand has a small water content, that is, it is a dry soil.

PORE SPACE AND AIR CONTENT. These also depend on the size of the particles. Large particles do not fit so closely together as do fine ones; hence sandy soils are porous, there is little tendency for the particles to stick together, and they are easy to work. Clay soils, on the other hand, are impervious, often waterlogged and sticky in wet weather, and heavy to work.

All cultivators of the soil try to improve its quality, to lighten heavy soils, and to make light soils more retentive. By digging, ploughing, &c., they break up the soil, renew the air supplies, and increase its porosity, keep down the weeds, &c.; by

manuring they supply any raw materials that are missing. Most of our fellow men, even in these days of town life, are tillers of the soil.

ORIGIN OF THE SOIL WATER. The water in the soil usually comes directly from the rain. Hence it is interesting to compare different soils, to see how much water they retain and how much of what falls on them they let through. Rain only percolates through the porous layers of the earth's crust; sooner or later it reaches impervious rocks on which it accumulates, forming the 'underground water table'. In dry weather plants depend on water sucked up from below for their supplies; if this water table is not too deep they may even get their roots down into it. When cutting the Suez Canal, many desert plants were found with roots going down 30 feet. The Mesquite, a tree of the Arizona desert, is said to send its roots down nearly 50 feet, and settlers use it to indicate the presence of underground water. Even if plant roots do not reach this underground table, water may rise from it into the upper layers of the soil in time of drought. This rise is due to a phenomenon known as *capillarity*, a fundamental property of water and similar liquids, which makes them rise in very narrow (capillary) tubes. The narrower the tube the greater the rise, hence it is obvious that clay soils can suck up water better than sandy ones. These facts are illustrated by the following experiments.

RETENTIVITY, POROSITY, AND CAPILLARITY OF DIFFERENT SOILS.

Experiment 44. To compare the retentivity of two samples of soil, take two glass funnels and fit them with perforated porcelain disks. On the disks place dry samples of the two soils to be compared, e.g. dry clay and dry sand. The two layers should be of the same depth. Support the funnels over two measuring-cylinders. Pour an equal volume of water simultaneously on to the two soils.

Observe: (1) Through which soil the water runs first. This is the *more porous*. Time the first drop.

(2) The volume of water that eventually comes through the two soils. This enables us to compare their *retentivities*. Some soils hold most of the rain that falls on them; others, with larger particles more loosely packed, let a great deal percolate through to lower levels.

Experiment 45. To compare the rise of water through two columns of dry soil, take two glass tubes, about 12 inches long and 1 inch in diameter. Tie muslin over one end of each, pack tightly with dry sand or clay, and stand the tubes with their ends in water.

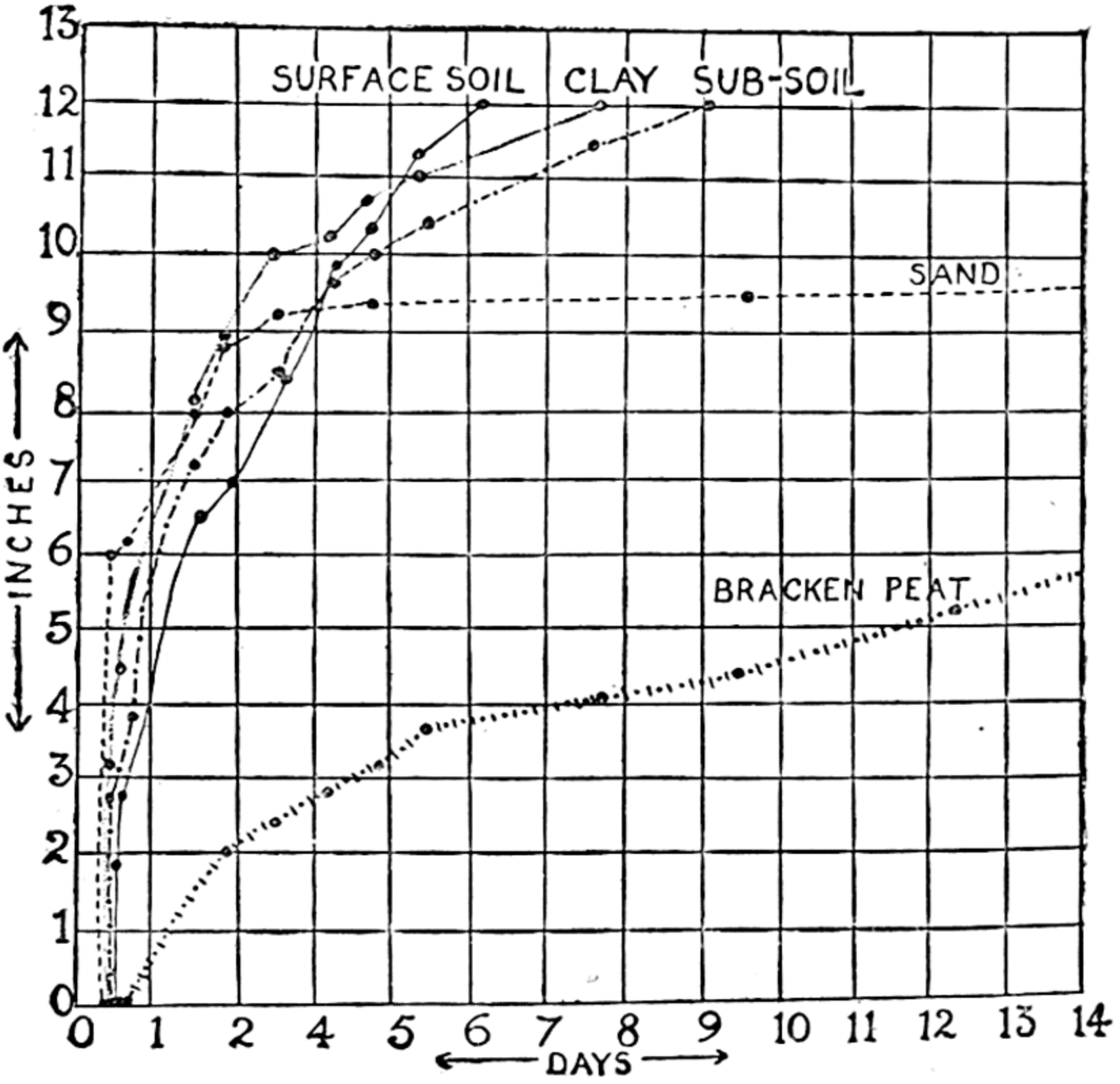


FIG. 27. Curves showing the rates at which water ascends in different soils

The water travels slowly upwards against gravity. Its height should be noted from time to time. The rise occurs more quickly in the sand, but the final height attained is greater in the clay (cp. Fig. 27).

SOIL. A SUMMARY. The top soil is formed by the weathering of permanent rock and an admixture of humus to the grains so formed.

The size of the soil particles varies in different soils, and many properties of the soil depend upon this size. Among these are its capacity for holding air and water, its porosity, the height to which water will rise through it in dry weather, its heaviness or lightness, &c.

The amount of nitrates and other soluble salts contained in the soil depends chiefly on:

(*a*) The nature and solubility of the contained minerals.
(*b*) The amount of humus present.
(*c*) The activity of bacteria.
(*d*) The manures which are added.

LIVING INHABITANTS OF THE SOIL. The soil has a teeming population. I do not now refer to the moles, foxes, rabbits, mice, toads, slugs, snails, insects, earthworms, threadworms, &c., which make their homes in the soil, though these are numerous enough. Darwin estimated, for example, that there are fifty thousand earthworms in every acre of garden soil, while a thimbleful of soil was found to contain thirty thousand threadworms. All these creatures, and especially the earthworms (cp. p. 151), play an important part in the formation of soil. But far outnumbering them all are the bacteria, minute organisms of the simplest possible form, but with extremely important functions.

BACTERIA are so small that we can see little of their structure. They are minute one-celled colourless plants, the cells spherical, rod-shaped, or curved. Apparently there is no typical nucleus, though particles of nucleoplasm seem to be scattered through the cell protoplasm, or even organized into a 'central body'. Tiny as these creatures are, they can grow and multiply at a tremendous rate; each cell enlarges and then divides into two by simple fission (cp. p. 37). As this division takes place under favourable circumstances at least every half-hour, the possible increase is prodigious. Some one calculated that, given favourable conditions, one bacterium could produce 7,000 tons of protoplasm in three days! Bacteria are active organisms, and many important chemical changes result from their activity They are not green. They can neither make their own food, like most plants, nor ingest

solids, like most animals. Many are *saprophytes*, i.e. they live on decaying organic matter; some are *parasitic*, i.e. they live as uninvited guests in or on the bodies of other living creatures (cp. p. 190). Parasitic bacteria, living in the human body, cause many infectious diseases.

SOIL BACTERIA. Of the bacteria living in the soil, two groups are of fundamental importance to plant life. They are known respectively as the *nitrifying* and *denitrifying* bacteria. It will be remembered (see p. 70) that green plants cannot use the nitrogen of the air for food production; they must be supplied with nitrates. Now nitrates do not occur to any extent in the rocks forming the earth's crust, and whenever a crop is taken from the soil that soil is depleted of its nitrate store. If this process continued indefinitely, cultivated soils would give poorer and poorer crops. This is happening in parts of India and China, and is a frequent cause of famine. But nitrogen supplies are renewed by wise cultivators, very largely by suitable manuring. There are, in addition, certain natural processes which help in the renewal (cp. Fig. 51).

BACTERIA AS SCAVENGERS. The fact that the earth is not littered with the dead remains of plants and animals is due to the beneficent action of myriads of saprophytic bacteria (and fungi), the world's most efficient scavengers. When dead bodies decay in the soil their proteins, &c., are broken down by bacterial action. The whole process is a gradual one, each step being the work of one group of bacteria. Eventually ammonia is formed; some of this gas escapes into the air; most of it becomes dissolved in the soil water.

Certain bacteria can decompose this ammonia. With oxygen from the air and limestone from the soil they may convert it into calcium nitrate. Potassium nitrate, sodium nitrate, &c., are other salts formed in a similar way. These nitrates are then ready for the use of the green plant; here is one way in which the nitrogen supplies in the soil can be renewed. When animal manures are added to the soil, they must always be decomposed in a similar manner before green plants can use them as a source of raw material.

DENITRIFYING BACTERIA. Unfortunately the break-down of

organic nitrogenous compounds does not always stop with their conversion into nitrates. Denitrifying bacteria may decompose the nitrates, producing free gaseous nitrogen; and free nitrogen, as we have already learned (cp. p. 70), is useless to most living organisms. Yet even here we find that other bacteria help, so that the nitrogen is not necessarily lost for ever to the world of living things. Such bacteria are called nitrogen-fixing.

NITROGEN-FIXING BACTERIA convert free nitrogen into nitrogenous compounds, which ultimately become available to green plants. These bacteria fall into two groups:

(1) There are some which live freely in the soil; these may be aerobic or anaerobic (see Chapter XXI). They 'fix' nitrogen, i.e. in the course of their living activities they cause it to combine with other elements to form nitrogenous compounds, as green cells cause carbon dioxide and water to combine to form carbohydrates. When the bacteria die and decay these nitrogenous substances are decomposed as described above, and here we have another way in which the nitrogen supplies of the soil may be gradually renewed.

(2) There are some nitrogen-fixing bacteria which are not free-living but inhabit the roots of certain green plants, particularly members of the family called Leguminosae, e.g. peas, beans, clover, sainfoin, lupins, &c. They penetrate the young roots, probably by entering the root-hairs, and cause characteristic swellings (nodules). Obtaining carbohydrates from the leguminous plants and also shelter in their tissues, these bacteria build up nitrogenous compounds from free nitrogen. These compounds are used by the leguminous plant. This is a third way in which the nitrogen supplies of the soil are gradually renewed. The farmer often grows a leguminous crop, e.g. peas or beans, and, having harvested the pods, ploughs the old plants into the soil, where they act as nitrogenous manure. The substances thus added to the soil represent 'fixed' atmospheric nitrogen.

Experiment 46. Dig up, wash, and examine the roots of leguminous plants, such as clover, lupin, sweet pea, &c., which are growing in ordinary garden soil. Notice and sketch the nodules.

Experiment 47. Shake up some soil with freshly distilled and therefore sterile water. Filter, divide the filtrate into equal portions, and sterilize one sample by boiling. Have ready three sterile test-tubes containing milk which has been sterilized by boiling. To one of these add the sterilized, to a second the unsterilized soil water. Plug all three tubes with cotton-wool and leave to stand. The milk to which unsterilized soil water has been added goes sour very quickly. We know that souring is due to the action of bacteria. Hence this experiment shows the presence of *bacteria in the soil.*

Experiment 48. Take a sample of garden soil, and divide it into two portions. Sterilize one part by leaving it for at least 48 hours spread out in the drying oven (dry at 100° C.). Sterilize some pots (set *A*) by washing in boiling water, pack these with the sterile soil, and plant in them bean and pea seeds. Plant similar seeds in pots (set *B*), filled with the non-sterile garden soil. Leave on a window ledge to grow for some months. (Be careful to water the sterile pots with sterile water only.) Then remove the plants, wash and examine the roots. The ones from set *B* will usually have nodules, while there will be none on the roots grown under more sterile conditions.

INFLUENCE OF THE SOIL ON THE DISTRIBUTION OF PLANTS AND ANIMALS. Soil and climate exert a great influence on vegetation. Forests can only flourish where there is an adequate water supply. On drier soils we find prairie, steppe, veldt, pampas, &c.—all the natural grass-lands of the world. The nature of the vegetation controls the conditions under which the animals inhabiting any region live, and hence the distribution of animals is largely dependent on the distribution of plants. Flowering plants have been classified, in respect of their water requirements, into three main groups:

1. *Hygrophytes*, which can only exist in soils containing at least 80 per cent. of water. This group includes the true water plants, or hydrophytes, which actually grow in water, as well as those of the swamp or marsh (cp. p. 83).
2. *Mesophytes*, which can only exist on soils containing from 80 to 20 per cent. of water.
3. *Xerophytes*, which are found on soil containing less than 20 per cent. of water.

These three groups of plants differ from one another in a marked degree. Some of the more striking characteristics of

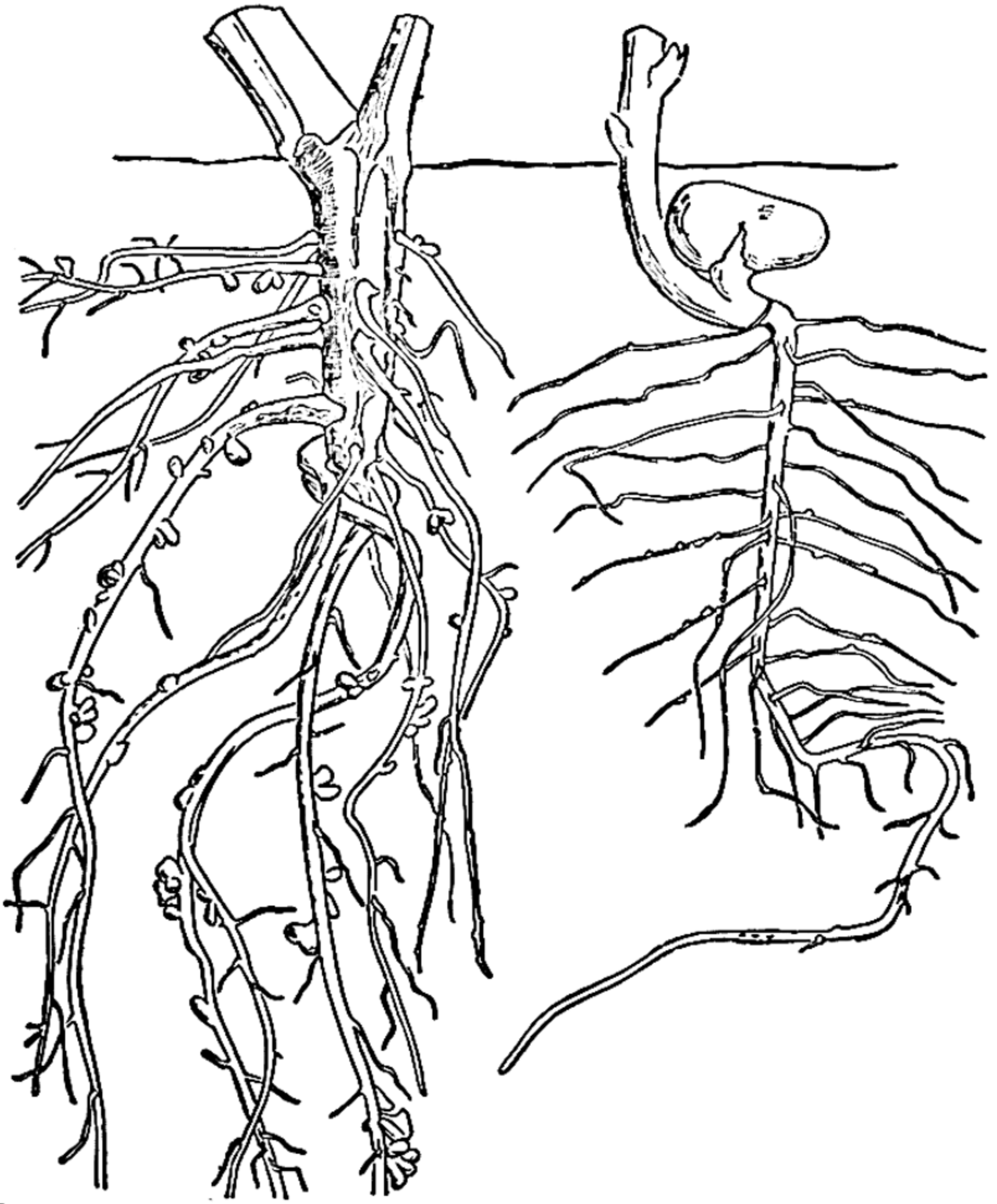


FIG. 28. ROOTS OF BROAD BEANS SHOWING NODULES. *Right*, a young plant with nodules beginning to show. *Left*, an older plant with nodules well developed. (Reduced)

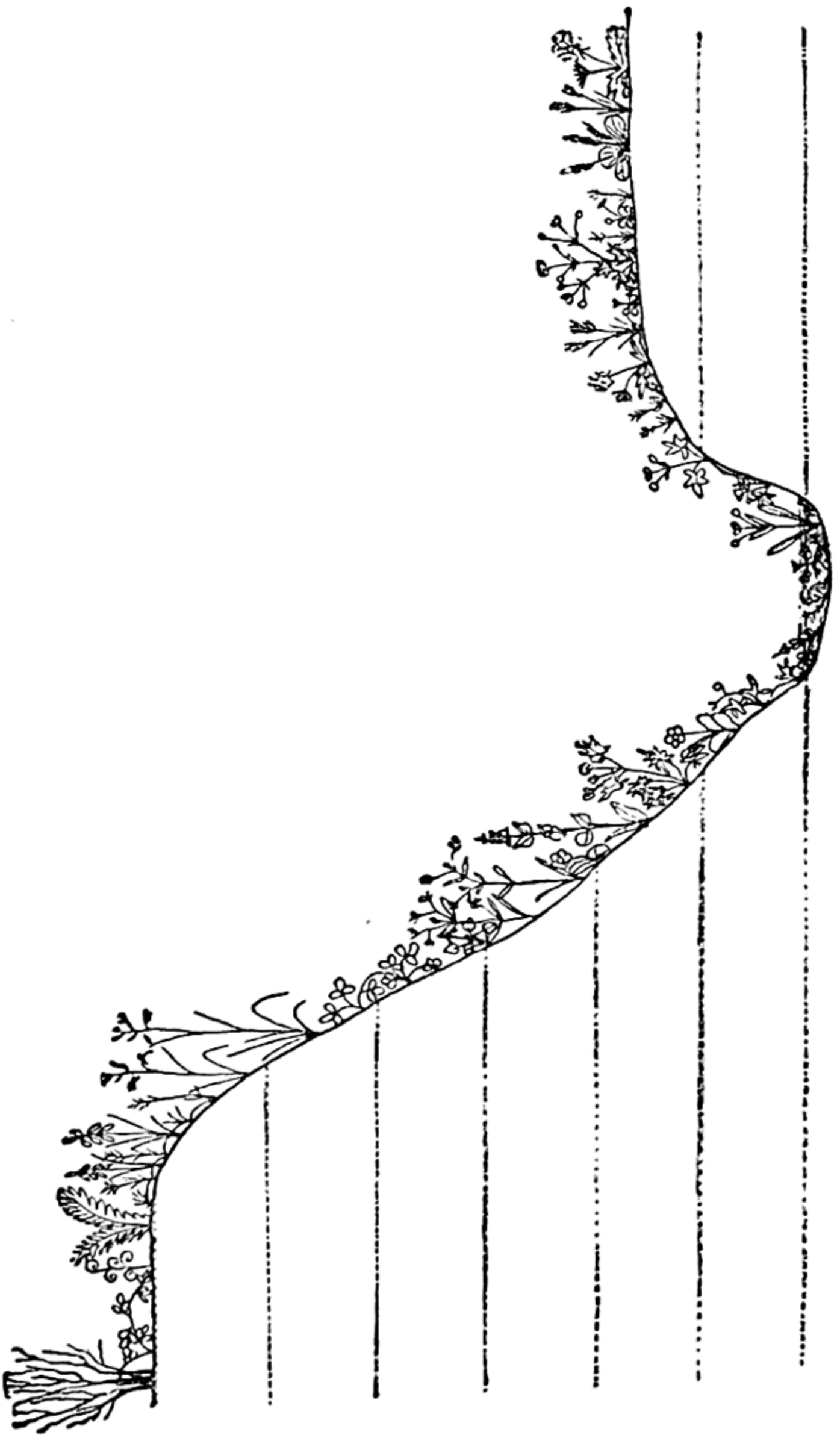


FIG. 29. Section through hedge, ditch, and meadow (see pp. 128–9)

hydrophytes (cp. pp. 272, 278), for example, are the reduction of root, reduction of conducting tissue, and increase of internal air-space which they display, combined with an absence of cuticle. Many of them possess more than one type of foliage leaf (cp. Fig. 79).

Xerophytes are often very striking plants. In England, as we have seen (cp. p. 110), we may study them on the sea-shore, on pebble beaches, on heaths and moors, and on the 'alpine' rockeries of our gardens. Growing in such places are typical xerophilous plants; they all have very characteristic leaves.

Exercise. The student should examine and draw such typical English xerophytes as samphire, stonecrop, houseleek, prickly saltwort, heather, &c.

XEROPHYTIC STRUCTURE.

Until recently we have believed that xerophytic modifications, such as reduction of leaf surface and other characters enumerated on p. 111, existed to check transpiration. A small leaf, other things being equal, obviously loses less water than a large one, a thick leaf more than a thin one. Such was the very plausible argument which you will find repeated in many text-books. But recent experiments have shown that many xerophytes do not transpire less than other plants (mesophytes) of the same size. The leaves may be small, but there are more of them. Xerophytes are able to live on dry soil primarily because, when the need arises, their protoplasm can be dried up to an extent which would kill the protoplasm of the ordinary mesophyte, and not because they necessarily lose less water by transpiration. We see once again the danger of making statements which have not been checked by accurate observation and experiment.

SOIL AND VEGETATION IN ENGLAND. In a small country like our own, where there are no great contrasts of climate, the direct influence of soil on vegetation is very obvious.

FOREST. On the chalk and limestone of southern England beech woods predominate, while ash occurs in similar situations farther north. On stiff clay we find the wet oak wood (where the pedunculate oak is the predominant tree); on drier sandy loams the dry oak wood (where the sessile oak is

predominant). It seems probable that England was once covered with forest belonging to one or other of these types, while northern Scotland had pine and fir woods.

It is obvious that the kind of forest depended primarily on the nature of the soil.

SCRUB OR HEATH. When these woods were cut down they were replaced by an equally characteristic vegetation, known as scrub or heath. Heaths are formed in this way on dry sands and gravels, heather, heaths, whortleberry, &c., being the most characteristic plants. Wet oak wood is replaced by prickly scrub, containing hawthorn, blackthorn, gorse, wild roses, blackberries, and many similar plants. On chalk the characteristic shrubs are white beam, spindle, elder, old man's beard, &c.

GRASS-LAND. This scrub is often replaced in its turn by grass-land. Much of our grass-land would probably return to scrub, and perhaps even to forest, if it were not for the activities of man and his domesticated animals. Horses, cattle, sheep, &c., crop the herbage so close to the soil that no bush can survive where they are turned out to feed.

Exercise. The student should study the soil of his own locality and the various plant formations which grow on it. If he has a wood, hedgerow, pond, or other characteristic association near at hand, he will find it both interesting and instructive to watch the area all through the year; to note the times and seasons of the various plant and animal inhabitants and to keep an illustrated record of their development; to photograph them if he has a camera; to make a vegetation map of a small portion of the area, putting in every plant and every animal found in it.

ECOLOGY, or the study of plants and animals in relation to their homes, is a branch of biology into which we cannot enter here. It is not a subject which can be learned up from text-books, but demands individual study in the field. Every student of biology should examine one or two special habitats, noticing how the plant and animal inhabitants are adapted to the special conditions that prevail.

A hedge, for example, is within the reach of all (cp. Appendix II). We can examine the plants that form it, the other plants that

grow up in its shelter, particularly the climbers that scramble over it to the light and air. Then there is its teeming animal population: the birds that nest in it in spring, shelter in it in rough weather, and eat the berries, nuts, &c., it provides; the spiders who spread their webs on its branches; the insects which, particularly in the larval stage (caterpillars, grubs), feed on its leaves; the snails and slugs; the little mammals (field-mice, hedgehogs, even rabbits, &c.) which shelter in the ground beneath (cp. pp. 527–31).

Such observations open up a whole new realm of knowledge. Many other habitats can be studied—woods, pastures, ponds and streams, the seashore, &c. (cp. Appendix II). Always we should make a list of the plant and animal inhabitants, should study their ways of life, their feeding habits, and their mutual interdependence on each other. The following questions, and reference to Appendix II, will guide you in these observations.

QUESTIONS ON CHAPTER XI

1. Give some account of the ways in which the higher plants may be modified either for life in water or under conditions of extreme dryness. (C.W.B.)

2. Give illustrated descriptions of three named plants characteristic of the sea coast or high moor or fresh water. (C.L.)

3. Describe the general form and habit of three plants which you have observed growing in a pond or stream, noting especially any features connected with the conditions under which they were growing. (J.M.B.)

4. Describe an experiment by which you would demonstrate the differences between (*a*) a 'heavy' and a 'light' soil, (*b*) a well-cultivated patch and the otherwise similar surrounding soil. In what ways does tillage improve the fertility of the soil? (L. Matric.)

5. Write a short account of the soil conditions of any plot of land that you have studied, and of the vegetation found there. (J.M.B.)

6. A year ago I dug into a garden plot a heavy dressing of strawy manure. On digging over the plot again a month ago I could not find a single unchanged straw; in fact, so far as the eye could see, the straw had entirely disappeared—some people would say it had 'rotted away'. Explain the disappearance of the straw. (J.M.B.)

7. Discuss the importance of soil bacteria. (Ox.L.)

8. Discuss the nature of the non-living components of an ordinary fertile soil. Which chemical constituents of the soil are essential for healthy plant growth? Describe an experiment by which you could determine the proportion of humus present in a sample of garden soil. (C.L.)

9. Give an account of the flora of a moor, and point out in which way the plants you name are adapted for life in such a situation. (L.G.S.)

10. What is meant by a plant community? Select any plant community you know well, and describe, in the first place, how the plants come to be there, and secondly, how it is that their roots and shoots fit in together without starvation or other injury. (L. Matric.)

11. Give an account of any plant community you have studied. In what ways are the plants adapted to the particular environment in which they live? (L.G.S.)

12. Describe the conditions of life either on a sand-dune or in a damp oak wood. Select any two plants which are found in the habitat which you describe, and point out how they are specially fitted to their environment. (L.G.S.)

13. Name the principal trees in any wood you have studied, and six herbaceous plants growing in this wood. State the time of year at which any *two* of the trees and any *two* of the herbaceous plants produce leaves and flowers. Sketch the whole external form of these two plants when in flower. (J.M.B.)

14. Give an account of the vegetation of a hedgerow *or* any small area of natural forest, *or* woodland, *or* moorland, *or* heath which you have studied. Describe the seasonal changes in the vegetation of the selected area. State where the area is situated. (C.L.)

15. *Either.* Write an account of any series of biological observations which you have carried out in a garden.

Or. Give a concise description of the plant life and the nature of the environment of any chalk down, *or* meadow, *or* lawn, *or* tropical savannah, *or* rain forest which you have studied. (C.L.)

16. Describe any piece of natural vegetation *or* cultivated ground you have studied. Mention the names of the *commonest* plants found there, and state for *two* of these plants the approximate dates when the following events occur:

(*a*) Unfolding of leaf buds, (*b*) opening of flower buds, (*c*) ripening of fruits, (*d*) fall of leaves. (Ox. & C.)

17. Give an account of the vegetation of any one plant habitat you have studied as it appears in (*a*) summer, (*b*) winter. (Ox. & C.)

SOME SUGGESTIONS FOR FURTHER READING

CHAPTER XI

The Meadow I Know
„ *Common* „
„ *Hedge* „
„ *Wood* „
„ *Pond* „
„ *Stream* „
} Westell and Turner. (Dent.)

The Sea Shore. Pycraft.
Mountain and Moorland. J. A. Thomson.
The Nature World of London. Johnson.
} (Sheldon Press.)

Beside the Brook. ('Country Life Series': O.U.P.)

Wayside and Woodland Blossoms
Wayside and Woodland Trees
} Step. (Warne.)

Life of Wayside and Woodland. Coward. (Warne.)

Pond Problems. Unwin. (C.U.P.)

Plant and Animal Oecology. Stork and Renouf. (Murray.)

Lessons on Soil. E. J. Russell. (C.U.P.)

Nature Study Guide. Furneaux.
Life in Ponds and Streams. Furneaux.
} (Longmans, Green & Co.)

Nature Study. D. W. Patton. (O.U.P.)

Rural Science. Mason and Dow. (McDougall's Educational Co.)

Science in the Country. W. B. Little. (Pitman.)

First Book of Nature Study. Stenhouse. (Macmillan.)

The Gateways of Knowledge. J. A. Dell. (C.U.P.)

Field Studies in Ecology
Ecology in Town and Classroom
} R. Bracher. (Arrowsmith.)

PART III
THE FOOD OF ANIMALS

CHAPTER XII
CAPTURE OF FOOD BY ANIMALS. THE PROCESSES OF DIGESTION

PLANT FOOD. In the last chapters we learned that food is made by green plants in the manner summarized below:

(1) $CO_2 + H_2O \rightarrow$ carbohydrates.

(2) $CO_2 + H_2O \rightarrow$ Oils and fats.

(3) Carbohydrates + nitrates, sulphates, and phosphates → proteins.

(4) Carbohydrates, fats, proteins, &c. → protoplasm.

ANIMAL FOOD. Now animals do not possess this power of manufacturing their own food from inorganic substances. They obtain all their food ready-made. This food, as we have seen (cp. p. 75), can always be traced back to the activity of some green plant. Sometimes the food chain uniting the animal with the plant on which it ultimately depends is a long one; for example:

Man → codfish → plaice → small shellfish → minute green plants in the sea.

Or: Man → milk → cow → grass.

All animals depend ultimately on plants for their existence.

FOOD-CAPTURE BY ANIMALS. Animals have to find their own food, and exhibit a great variety of feeding mechanisms. The structure and habits of the animal are intimately connected with its method of feeding. The apparatus for the capture of food varies with the food used. The cat, like all carnivores, is stealthy in its movements, its padded feet facilitating a soundless approach to its prey. It has sharp teeth (cp. Fig. 39 C), claws which can be withdrawn so that they make no sound during movement, and highly developed sense organs, all adaptations which aid in the catching of the prey. Contrast it

with the more passive, hoofed, flat-toothed (cp. Figs. 39 A and B), herbivorous cow, which crops grass, swallows it without mastication into the first of its four 'stomachs', only to return it later to its mouth, to 'chew the cud' at leisure. This way of food-getting is very well suited to animals which are the hunted, not the hunters. It enables them to crop their bulky vegetable food as speedily as possible; they can then retire to a safe place to chew and digest it without fear of interruption.

Birds of prey may be compared with carnivorous mammals; they have sharp talons, hooked beaks, and powerful wings (eagles, owls, &c.). It requires very little study to show that there is, in all birds, a striking correlation between their way of life and the structure of their various organs, feet, beaks, wings, &c.

As we continue our study of animals, we shall discover many adaptations which aid them in the difficult task of food-capture. The life of an animal is passed largely in a search for suitable food, and in the constant endeavour to escape from its enemies.

ANIMAL MOVEMENT AND ITS CO-ORDINATION. Animals must move about in search of food, and the study of animal movement, and of the protective colorations and other camouflages which help them to escape their enemies and to stalk their prey, is one of extraordinary interest. They can walk, run, leap, hop, creep, swim, fly, and so on, by which movements they seek their food. The whole body of the animal is more highly differentiated than that of the plant. It is usually of definite shape, compact, and graceful in form, and of limited size. Its responses are very rapid. This is particularly noticeable in the higher animals, in which so many organs act in harmony in the hunt for food. Watch the cat stalking a bird, or the gull pouncing on a fish. To bring about the co-ordination of its many activities, the higher animal possesses a nervous system by which the parts of the body are made to work in unison, and definite sense organs by which it receives stimuli from the outside world. We shall return to a study of these structures in a subsequent chapter (cp. Chapters XVIII and XIX).

In all these features there is a marked contrast between the animal and the plant. The plant can be much more passive than the animal, for it has merely to spread out its green cells to the light and air and to thrust its roots down into the soil. Hence its body is spreading and indefinite in shape and it grows all through life. Its responses, even those of the highest plants, are slow and much less varied than those of the animal (cp. Chapter XX). These constant differences between the typical plant and the typical animal (cp. p. 31) are closely connected with the very different ways in which the two organisms obtain food. *This difference in nutrition is the fundamental difference between plants and animals.*

DIGESTION OF FOOD. The food captured by an animal cannot at once be incorporated into its protoplasm. Smith minimus, the new-born baby weighing about 7 lb., grows into Smith major, weighing perhaps 11 or 12 stone. A certain amount of his food is used to make new 'Smith' protoplasm. It follows that the bread and cheese, ham and eggs, roast beef and Yorkshire pudding—all the diverse substances which Smith will devour in the course of his life—must undergo very considerable chemical and physical changes before they can be incorporated into his protoplasm. We call these changes *digestion and assimilation.*

Digestion, like respiration, excretion, and other characteristic living activities, is a process common to plants and animals. We have, for example, examined the solid starch grains in the cells of a bean cotyledon and a green leaf (cp. Fig. 18). Such solid granules cannot escape from the storage cells. They must first of all be digested, i.e. changed into substances that are soluble in water and whose molecules are small enough to diffuse from cell to cell (cp. p. 78 et seq.). When once the molecules are sufficiently small, usually neither the protoplasm nor the cellulose wall offers any barrier to their passage.

ANIMAL DIGESTION AND ASSIMILATION. Animal food must likewise be digested. When any creature has captured its food, it is only at the beginning of the chain of events which will lead to the renewal of its supplies. The food is usually swallowed

into an internal cavity or tube, *the gut or alimentary canal* in its broadest sense. This gut is merely a space within which the food can conveniently undergo digestion. Only when quite soluble can it pass through the wall of the food canal to be used by the body cells. Indeed, some food never gets to those cells at all. This is the fate of all indigestible matter, which is simply expelled as faeces from the gut cavity.

Since animals feed on 'foreign' food, they must not only digest their food but assimilate it. Grass proteins, for example, are not bullock proteins, nor are bullock (beef) proteins identical with human ones. Each animal must build up from its food the exact chemical compounds its body requires. This is the process known as assimilation.

We now turn to carry out a few experiments which will teach us something about the nature of digestion.

DIGESTION OF STARCH. Let us first try to discover what happens to the starch which is found as a reserve food in so many plants.

Experiment 49. Cover some dry, ungerminated barley grains with distilled water, and crush in a pestle and mortar. Pour off some of the milky fluid into two test-tubes, and test one sample for starch with iodine solution, the other for sugar with Fehling's solution. The barley grains contain stored starch, but no sugar.

Experiment 50. Repeat the previous experiment, using sprouting grains with radicles 5–10 inches long instead of dormant ones. (N.B. The grains are germinated in the dark.) Abundant sugar is present in the seedlings.

Experiment 51. Examine (*a*) ungerminated and (*b*) germinating broad-bean seeds for starch and sugar. Chop up the parts to be tested, and place the fragments in test-tubes. In (*b*) test the radicle and plumule as well as the cotyledons. Starch is present in the resting embryo, but no sugar. After germination in the dark sugar is present as well, particularly in the young plant axis.

Experiment 52. Repeat the previous experiment, using (*a*) a dormant potato tuber, which has been stored in a cold, dry place, (*b*) a tuber which, having been kept moist, warm, and in the dark for some weeks, has begun to sprout.

Once more we find that the dormant structure contains abundant starch, but little or no sugar. There is much more sugar in the sprouting tuber, especially in and near the growing shoots (eyes).

STARCH TRANSFORMED TO SUGAR. The above experiments all illustrate a process of digestion. Insoluble starch is transformed to sugar, which is both soluble and diffusible. What causes this change? What is it, for example, which makes starch, which has been inert all winter in a barley seed, begin to change to sugar when that seed is planted in the spring?

Starch may be converted to sugar in the laboratory in the following way:

Experiment 53. Prepare a starch paste, by weighing out 1 gm. of dry potato starch; add a little cold distilled water (about 10 c.c.). Stir vigorously and pour on about 90 c.c. of boiling water. Boil for a minute, stirring all the time. Allow to cool.

Put some of this paste into two separate beakers and, having added a few drops of strong hydrochloric acid to the contents of one beaker (*A*), put both on to boil. Remove samples of the two liquids at intervals and test for starch and sugar. The results of tests on the contents of *A* would be similar to those given below, while in beaker *B* no such changes occur.

Time	*Effect of iodine test*	*Effect of Fehling's test*
About 4 minutes	Blue coloration	No red precipitate
„ 8 „	Red-brown coloration (denoting dextrin)	A trace of red precipitate
„ 12 „	Yellow-brown coloration	A distinct „ „
„ 16 „	No coloration	Increased „ „

Evidently the starch in *A* has been decomposed, as the result of the combined action of the heat and the acidulated water. It is gradually transformed to sugar, passing through various intermediate stages in the process.

The laboratory method just described, which involves prolonged boiling, is obviously not the way in which starch is converted to sugar in living cells. How do such cells carry out this process?

DIGESTION THE WORK OF ENZYMES. Digestion is brought about by certain substances called enzymes. These are probably present in all living cells and may play a part in every vital activity. They are substances of organic nature, which can

be extracted from the cells and still retain their power. These enzymes have many characteristic properties, which we may summarize as follows:

I. They are made by living protoplasm, but are not themselves alive.

II. They occur in large numbers, each enzyme being specific in its action, i.e. it acts on one kind of foodstuff only, and brings about one quite definite chemical change.

III. The action is reversible; e.g. if an enzyme changes starch to sugar when there is abundant starch and little sugar, it will also transform sugar to starch where there is plenty of sugar and little starch. Hence, in a rapidly assimilating green leaf, sugar is being continually transformed to starch (cp. p. 64). But after sundown, when sugar is no longer being formed, the stored starch is gradually, by the same enzyme, changed back to sugar.

IV. The enzyme remains unaltered during the action.

V. Hence small quantities of an enzyme can change large amounts of food.

VI. Enzymes act best in a definite medium, some requiring an acid, some an alkaline, and others a neutral solution.

VII. The enzyme is usually destroyed by heating above 50° C.

CLASSIFICATION OF THE ENZYMES. The exact chemical composition of these substances is not yet known, so we can best classify them according to the kind of food on which they act.

Carbohydrases are the enzymes which act on some carbohydrate.

Lipases are those enzymes which act on oil or fat.

Proteases are the enzymes which act on proteins.

HISTORICAL. It is striking how little was known about digestion until comparatively recent times. The processes of fermentation (cp. p. 263), which are also due to enzyme action, were familiar in remote antiquity, but many centuries were to elapse before the nature of these processes became at all clear. One of the first recorded scientific experiments on human digestion was performed by the Abbot Spallanzani (1729–99). He enclosed meat in perforated metal balls, then

swallowed the balls, recovered them from the faeces after they had passed through his alimentary canal, and examined the meat to see what changes it had undergone. Since that time our knowledge of enzymes has been greatly increased.

ENZYME EXTRACTS. Enzymes are particularly abundant in the digestive juices of the higher animals. They are also present in comparatively large quantities in rapidly growing plant tissues; the awakening of dormant seeds, &c., is always accompanied by a great increase in enzyme activity. These substances are easily extracted from the bruised or finely minced tissues of plants and animals. If, for example, we grind up germinating barley seeds in water, and filter off the fluid so obtained, this liquid contains an enzyme, called *diastase of malt*, which affects starch, transforming it to sugar. Many of these extracts can be bought from the chemist; one of the best-known being *rennet*, which is used for making junket. They are useful in medicine, and also in many industries. Let us now study their action by suitable experiments. We shall require:

i. *Diastase of malt*, a greyish powder obtained by a process of extraction from germinating barley seeds.
ii. *Liquor pancreaticus*, a liquid extract from the mammalian pancreas.
iii. *Liquor pepticus*, a liquid extract, or *pepsin flakes*, a solid preparation, from the stomach.
iv. *Lipase*, a powder obtained from an extract of the mammalian pancreas.

EXPERIMENTS WITH ENZYMES AND ENZYME EXTRACTS.

Experiment 54. Add a pinch of diastase of malt to some starch paste (cp. exp. 53) in a test-tube. Keep this at about 40° C., remove samples of the paste at intervals of 15 minutes (or leave until the next lesson), and test for starch and sugar. After a short time the sugar test gives a positive result. In a control tube containing starch paste only, no sugar appears. The enzyme extract has converted the starch to sugar.

The most easily obtainable enzyme-containing fluid in our own bodies is the saliva of the mouth. Let us examine its action.

Experiment 55. Take a mouthful of warm water, wash round the mouth for at least a minute, and collect the liquid, which contains saliva, in a clean test-tube.

Add some of this liquid to starch paste to which a trace of common salt has been added. Add some boiled saliva-containing liquid to a second sample of starch paste.

Keep the tubes warm (35–40° C.) by immersing them in a water-bath. Remove samples of the solutions at intervals, and test for starch and sugar. At first they both contain starch. Later a reducing sugar appears in the one tube, but not in the other; this tube, in the end, does not give the reaction for starch, though this reaction is obtained unaltered in the control tube.

ACTION OF SALIVA. We learn that saliva, given suitable conditions of temperature, &c., converts starch to a reducing sugar (maltose). Its action is destroyed by boiling.

The effect of the enzyme (called ptyalin) is to split the large starch molecule, whose chemical formula, still unknown, is probably approximately $C_{1200}H_{2000}O_{1000}$, into a number of smaller molecules of the sugar maltose, a disaccharide (cp. p. 142), whose formula is $C_{12}H_{22}O_{11}$. At the same time water is added, so that we have here an example of a well-known chemical process called hydrolysis. Ptyalin is an enzyme which acts chiefly on boiled starch.

Experiment 56. Add 'liquor pancreaticus', an extract from the pancreas of the pig, to starch paste, keep at 40° C., and test as before. The starch is converted to sugar.

To illustrate the fact that one effect of enzyme action is to convert indiffusible substances into diffusible materials, we may set up the following experiment.

Experiment 57. Soften two Whatman's diffusion shells by soaking them in water. Fill both with starch paste, add diastase to one (*A*), but not the other (*B*). Plug the shells with cotton-wool. Suspend them in two beakers of distilled water, and set aside in a warm place. After some time remove the shells, concentrate the water in the two beakers, and test for starch and sugar.

No starch is present in either sample. The large starch molecule cannot diffuse through the parchment shell. The water round *A* contains sugar. Formed from the starch by the diastase, it has diffused out from the shell.

EXPERIMENTS WITH PROTEASES.

Experiment 58. Chop up some boiled egg-white or, better, pass it through a fine sieve. Test a little by the Biuret test, and notice the violet coloration (cp. p. 54). Now add to a sample of the egg-white some 'liquor pepticus', and keep the test-tube warm. After half an hour notice that the liquid looks clearer. The egg-white is going into solution. Pour off this solution and repeat the Biuret test. A rose-red colour is obtained in place of the violet. This is a test for *peptones*. The protein is being split up into peptones, nitrogenous compounds of simpler chemical nature, which are both soluble and diffusible.

Experiment 59. Put some chopped-up egg-white into two Whatman diffusion shells. Add a 0·4 per cent. solution of hydrochloric acid to both (since the enzyme *pepsin*, contained in 'liquor pepticus', requires an acid medium for its action; cp. p. 137). Add 'liquor pepticus' to one of the tubes, plug both with cotton-wool, immerse the lower end of each shell in a beaker of distilled water, and keep both in a warm place. After 24 hours the water surrounding the one shell will, if the Biuret test be applied, yield the rose-red colour characteristic of peptones. No reaction is obtained when the test is applied to the water surrounding the other tube, the one to which no enzyme was added.

Once more we learn that digestion, by reducing the size of the molecules, enables food to pass through membranes which are impermeable to the original food substance.

Experiment 60. To show that pepsin requires an acid medium for its action place equal amounts of fibrin (a protein prepared from blood) in three test-tubes, labelled *A*, *B*, *C*. Add to *A* a small volume (say 5 c.c.) of pepsin solution (or a somewhat larger volume of 'liquor pepticus') and an equal volume of a 0·4 per cent. solution of hydrochloric acid.

To *B* the same volumes of *boiled* pepsin and of 0·4 per cent. HCl.

To *C* the same amount of pepsin (unboiled), but replace the 0·4 per cent. solution of HCl by an equal volume of *distilled water*. Place all three tubes in a water-bath (40° C. is best). Observe carefully the changes that occur, and you will find that the fibrin gradually swells, becomes transparent, and eventually completely dissolves in *A*. It remains unaltered in *B* and *C*.

This shows that neither the pepsin alone nor the acid alone can digest fibrin, but that the *pepsin can only act in an acid medium*.

EXPERIMENTS WITH LIPASES.

Experiment 61. Take two test-tubes and put into each a little olive-oil and water; add to one a few drops of caustic potash, and shake. The one liquid has formed a permanent emulsion; it is a milky fluid. In the other test-tube, oil and water separate again—no permanent emulsion has been formed.

Emulsification plays an important part in the digestion of fats; the fats, when emulsified, are broken up into minute droplets, which present a very large surface to the enzyme, and so make the fat more susceptible to the action of the lipase.

Experiment 62. Shake up some olive-oil, water, and lipase in a test-tube, and leave to stand. Compare this with a second tube to which no lipase has been added. The oil and water mix in the first tube, and the oil is no longer visible. There is no mixing in the second. This shows that the lipase has begun to digest the fat.

EXPERIMENTS ON DIGESTION. A SUMMARY. The above experiments serve to illustrate the processes at work wherever food is digested, whether in plant or animal. In every case it is made soluble and diffusible by enzyme action. In a few plants and in the majority of animals this digestion is carried out by definite digestive organs whose structure is specialized for that particular purpose. These organs exhibit every gradation of structure from the very simple to the extremely complex. In vertebrate animals the alimentary canal is very highly developed. We shall return to the study of these matters in the following chapters.

THE CHEMICAL COMPOSITION OF CERTAIN FOODS IN RELATION TO ENZYME ACTION. Digestion is very largely a chemical process in which the enzyme acts as does a catalyst in many chemical reactions; hence, for a more detailed study of digestion a greater knowledge of chemistry is desirable than will be possessed by most readers of this book. Yet the following general facts are not difficult, and, if understood, they greatly help in the study of our own processes of digestion.

The molecules of all the more complex foodstuffs are aggregates of some much smaller unit, just as certain artistic designs, certain musical compositions, &c., are formed by the linking

up of many 'repeats' of some simpler theme which forms the basis of the more elaborate structure.

THE PROTEINS AND PROTEASES. Protein molecules, for example, consist of a large number of amino-acid groups. An amino-acid is a fairly simple nitrogenous compound, and it seems certain that, in the synthesis of proteins by green plants (cp. p. 74), amino-acids are formed first, proteins being derived from them by the condensation and linking up of a large number of amino-acid groups; this condensation is the work of enzymes. The amino-acids will diffuse, but the large protein molecules thus formed are usually indiffusible.

THE DIGESTION OF PROTEINS. In the digestion of proteins these processes are more or less reversed, the molecules being split up by the appropriate enzymes into smaller and smaller units, until finally amino-acids are formed once more. This splitting always involves the addition of a certain number of molecules of water (hydrolysis).

Proteolytic enzymes fall into three main groups:

1. *Pepsins* are enzymes which convert proteins to peptones, soluble substances with a much smaller molecule than the proteins from which they are derived.

2. *Erepsins* can convert the peptones to amino-acids.

3. *Trypsins* are enzymes which can bring about the complete conversion of protein to amino-acid. Proteins are generally reduced to amino-acids in the course of animal digestion.

CARBOHYDRATES AND CARBOHYDRASES. The more complex carbohydrates may be regarded as the product of a condensation of many sugar molecules, just as proteins are formed by a condensation of amino-acids. We have learned that the simplest sugars, called *mono-saccharides*, have the formula $C_6H_{12}O_6$ (cp. p. 54). A large number of these sugars are known; there are, for example, at least thirty forms of glucose alone. They differ in the way the constituent atoms are arranged in space, in what we might call the pattern of the molecule, and not in the number of its constituent atoms.

Two monosaccharide molecules may be condensed, with the elimination of a molecule of water, to give a *di-saccharide* sugar;

$2C_6H_{12}O_6 - H_2O = C_{12}H_{22}O_{11}$. Sucrose (cane sugar), lactose (milk sugar), and maltose (formed during the digestion of starch) are familiar disaccharides.

A further condensation of disaccharide molecules, with the elimination of more water, gives the *poly-saccharides* $(C_6H_{10}O_5)_x$. Familiar polysaccharides are starch, glycogen or animal starch, and cellulose.

THE DIGESTION OF CARBOHYDRATES. The digestion of these large-moleculed carbohydrates is again a process of splitting up the molecule with the addition of water. Polysaccharides are reduced to disaccharides, and disaccharides to monosaccharides. The chief enzymes which digest carbohydrates, with the products they form, are given below:

Poly-saccharides	*Enzyme*	*Disaccharides*	*Enzyme*	*Mono-saccharides*
Starch	Amylase*	Maltose	Maltase	Glucose, 2 types
Cellulose	Cellulase, also called Cytase	Cellobiose	Cellobiase	Glucose
Glycogen	Glycogenase	Maltose	Maltase	Glucose (2)
		Lactose (milk sugar)	Lactase	Galactose, Glucose
		Sucrose (cane sugar)	Sucrase (also called Invertase)	Glucose, Fructose

* Ptyalin, the enzyme found in saliva (cp. p. 139), is often called salivary amylase since it belongs to this group. These old names (e.g. ptyalin) were given before anything was known of the chemistry of these substances. As our knowledge increases a new method of naming them will undoubtedly be adopted.

We see that the digestion of a polysaccharide is a complex process, in which at least two enzymes participate. The end result is the formation of a soluble and diffusible monosaccharide sugar.

QUESTIONS ON CHAPTER XII

1. How do plants obtain their food? Of what substances does this food consist? In what ways does it differ from the food used by animals? (C.L.)

2. Describe the mode of feeding of (*a*) an amoeba, (*b*) Spirogyra, and point out why the former is called an animal, the latter a plant.

3. Write a short essay on 'Nutrition and the Interdependence of Plants and Animals'. (L.G.S.)

4. Write a short essay on animal food, and describe, for three named animals, the ways in which they capture their food. If possible, the second part of your essay should be based on personal observation.

5. What do you understand by digestion? Describe three experiments which throw light on this process.

6. What are enzymes, and what are their chief characteristics? Name the chief classes of digestive enzymes, and say what you know of their action.

7. How is starch digested? Describe two experiments which illustrate this process, one showing digestion in a plant cell and the other digestion by an animal.

8. Write a short essay on proteins, saying what you know of their manufacture and their use to the living cell.

9. What do you know about the digestion of proteins? Describe any two experiments which support your statements.

10. What do you understand by (1) an enzyme, (2) a protein, (3) an amino-acid, (4) a polysaccharide, (5) a monosaccharide?

11. In what parts of a plant may food be stored? Mention definite examples in each case. State the nature of the principal stored material. Explain how such food resources are rendered available for use by the plant. (Ox.L.)

12. Write a short essay on the ways in which plants and animals are dependent on one another. (L.G.S.)

13. Write short explanatory notes on the following: pupa, secretion, chlorophyll, digestion. (L.G.S.)

14. Explain briefly the importance of ferments (enzymes) in the life processes of organisms, and give one example each from plant and animal life, explaining fully their uses to the organism. Are enzymes living substances and can they work when removed from the body? (Ox.L.)

CHAPTER XIII

FOOD-CAPTURE. DIGESTIVE ORGANS AND PROCESSES OF DIGESTION IN CERTAIN INVERTEBRATE ANIMALS

INCREASING COMPLEXITY OF DIGESTIVE ORGANS. A study of the digestive organs of animals reveals an advancing complexity as we pass from the lower to the higher forms.

In the Amoeba (Fig. 7), there is merely a temporary food vacuole in which the food remains until it has been digested and absorbed. Any indigestible residue is voided at a temporary aperture.

HYDRA. This is a small fresh-water animal, multicellular, and with a body which is more highly organized than that of Amoeba. Several species may be found in British ponds, all very similar in structure.



FIG. 30. Two specimens of Hydra, one contracted, the other extended, as when it is 'fishing' for food. The latter has two buds

Exercise. Examine a living hydra (*a*) with a lens, (*b*) under a low-power microscope.

The little creature is about 6 or 7 mm. long when fully extended; one end is usually attached to a water weed; at the other (free) end there is a mouth surrounded by a ring of tentacles (see Fig. 31). This mouth, the only external aperture, leads into

a central cavity, the digestive cavity or coelenteron, which even extends into the tentacles. The body-wall which encloses this cavity consists of two layers of cells only, an outer ectoderm and an inner endoderm.

FOOD-CAPTURE IN HYDRA. Hydra lives chiefly on tiny 'water-fleas', on fish eggs, &c., for which it 'fishes' with its extended tentacles. Among the ectoderm cells are small stinging cells, called cnidoblasts; these are particularly numerous on the tentacles, where they are grouped in 'batteries'. From each such cell a hollow, thread-like dart can be ejected, which is shot out at the animal that is being captured (cp. Fig. 33). This becomes entangled in the thread, which acts as a 'lasso', while a little poison may also be injected into it. Numb, or already dead, the unfortunate victim is swept by the movement of the tentacles into the mouth, which opens widely to receive it.

DIGESTION IN HYDRA. Once within the gut cavity, the Hydra digests its food in one of two ways. Certain endoderm cells may thrust out pseudopodia into the cavity of the coelenteron and ingest solid particles. Such solids, chiefly partly digested substances, undergo complete digestion *within* the cells that engulf them. The mechanism here is similar to that found in Amoeba; it is intra-cellular.

On the other hand, enzymes may be poured into the gut cavity itself by the cells adjacent to it; a protease and probably a lipase are secreted in this way, the secretory cells being found in the endoderm, chiefly near the mouth. Meanwhile flagellae keep the food in motion so that it becomes thoroughly stirred up. We have here a mechanism which may be compared to that of the higher animals, the coelenteron or gut representing a true digestive cavity; within it solid food is made soluble and diffusible, so that it can be absorbed. Any indigestible residue is voided by the mouth; there is no anus in Hydra.

HYDRA HAS NO CIRCULATORY SYSTEM. Once it has been absorbed into the body cells, food can pass quite easily from one cell to another. No circulatory system is necessary in so simple an organism. It has, however, a primitive nervous system

by which the activities of its various cells are co-ordinated. (Cp. p. 209.) For the creature is an individual, in which the cells of the body are acting in the interest of the whole organism. They are like the separate instruments of an orchestra, each playing its own essential part, yet each subordinate to the whole. The

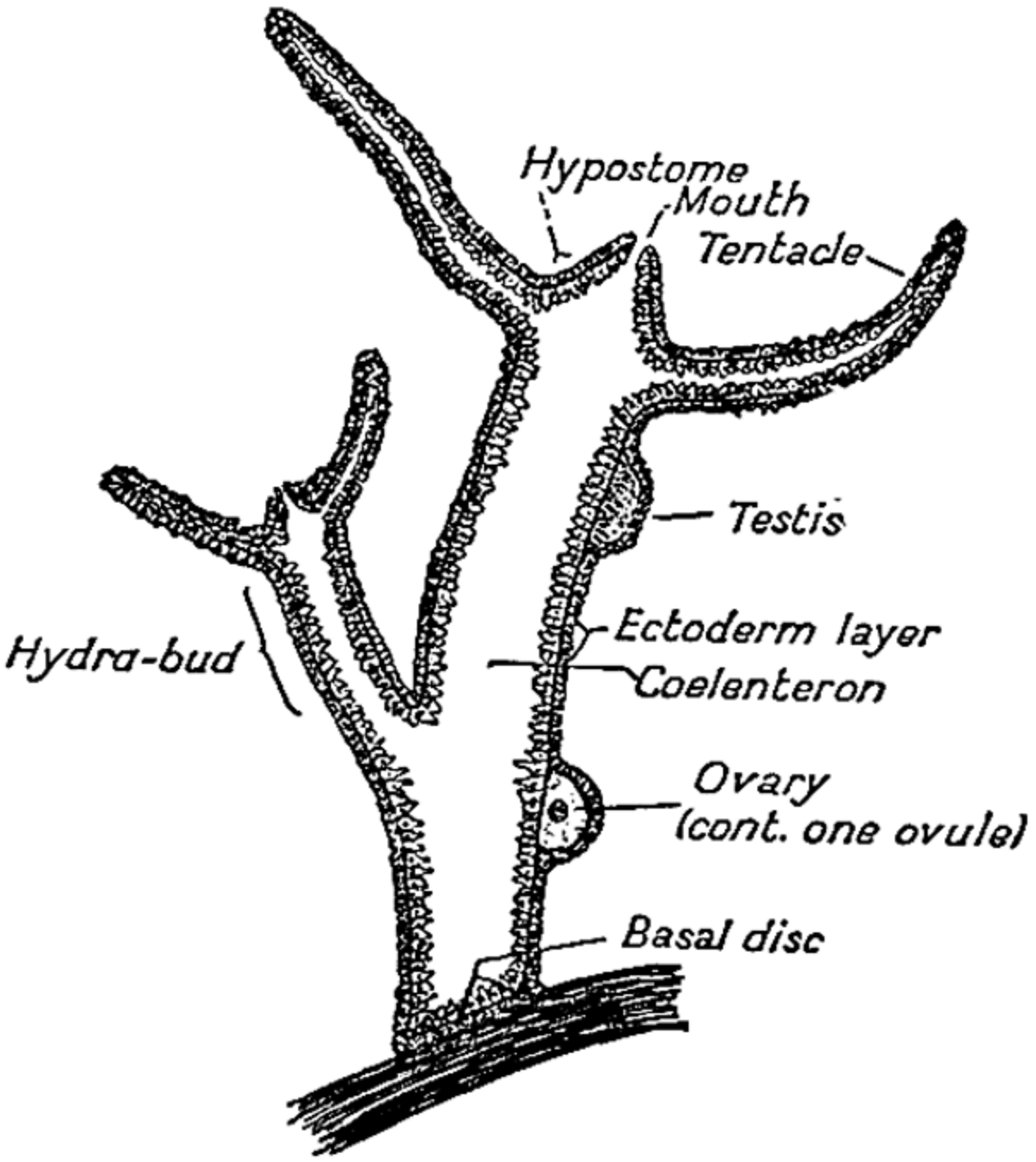


FIG. 31. Longitudinal section of a hydra (diagrammatic)

conductor's baton co-ordinates the actions of the individual players, the nervous system that of the individual cells. How well these act together in the body of a hydra is seen very clearly when we study its movements.

MOVEMENTS IN HYDRA. A hydra is capable of fairly rapid movement. When examining it under the microscope you will have observed that it contracts, when disturbed, until its body is almost globular, with the tentacles protruding as little blunt knobs. It is by such contractions and extensions of the body

cells, particularly those of the tentacles, that it 'fishes' for its actively moving 'food' (cp. Fig. 30).

Occasionally the animal moves from one place to another. Sometimes it does this by sliding along on its base; sometimes it bends over, fixes itself by its 'head' end, draws its 'foot' end up towards its mouth, and then straightens itself again, moving in the manner of a 'looper' caterpillar (cp. Fig. 32); sometimes

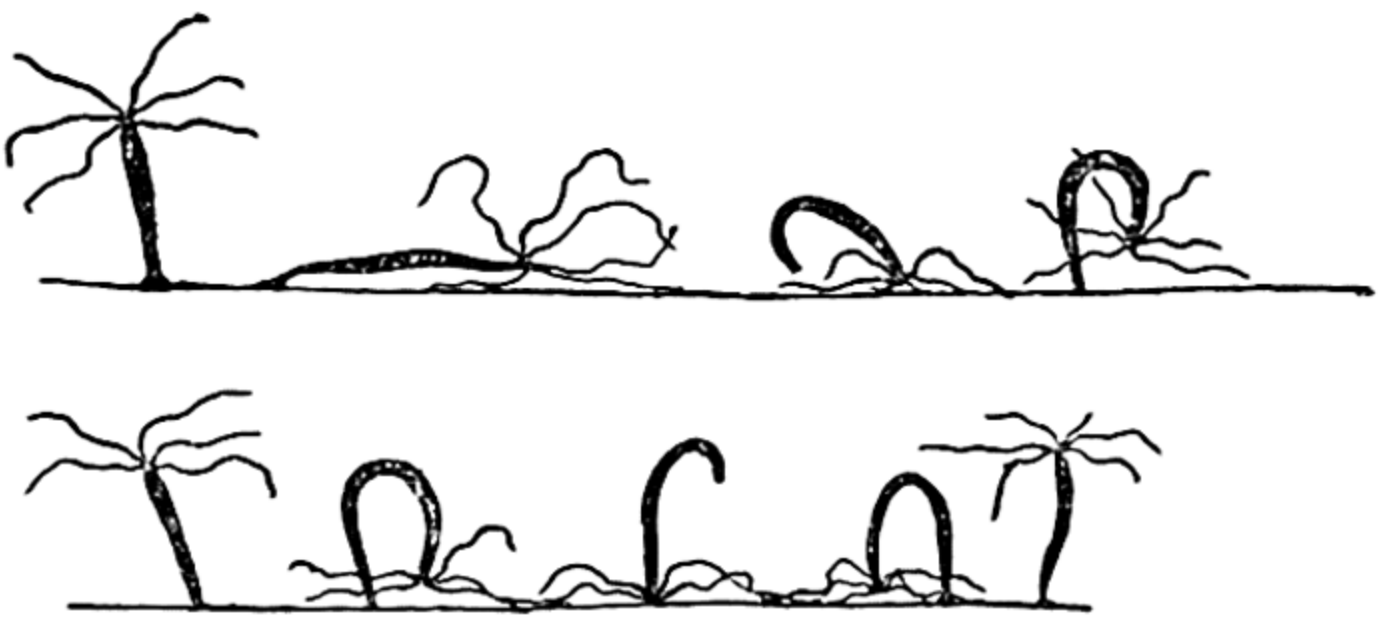


FIG. 32. The movements of locomotion in Hydra

it may literally 'turn head over heels'. It can also 'swim' through the water.

Obviously it is not only in its feeding mechanism that Hydra is more 'specialized', more 'highly organized', than an amoeba. Indeed, by studying this creature we begin to understand what the biologist means by these terms.

SPECIALIZATION AND DIVISION OF LABOUR IN HYDRA. In multicellular animals the cells of the body are never all alike, but are specialized to perform different functions, e.g. muscle cells to contract and cause movement, gland cells to secrete useful substances such as digestive juices, skin cells to protect the whole body, bone cells to lay down supporting material, special reproductive cells to carry on the race, and so on.

In Hydra we see this process beginning. Its various cells are shown in Fig. 33. The whole *ectoderm* is protective and is endowed with great power of contraction, but its cells cannot, for example, ingest solid food. They are specialized for certain functions only.

Among the cells forming this layer are:

(*a*) Cells whose inner ends are drawn out into long 'muscle tails'.

These tails run parallel to the long axis of the body, so that when they contract the whole animal shortens.

(*b*) The cnidoblasts, which help the creature to capture its food. From each of these there projects at the surface of the animal a short

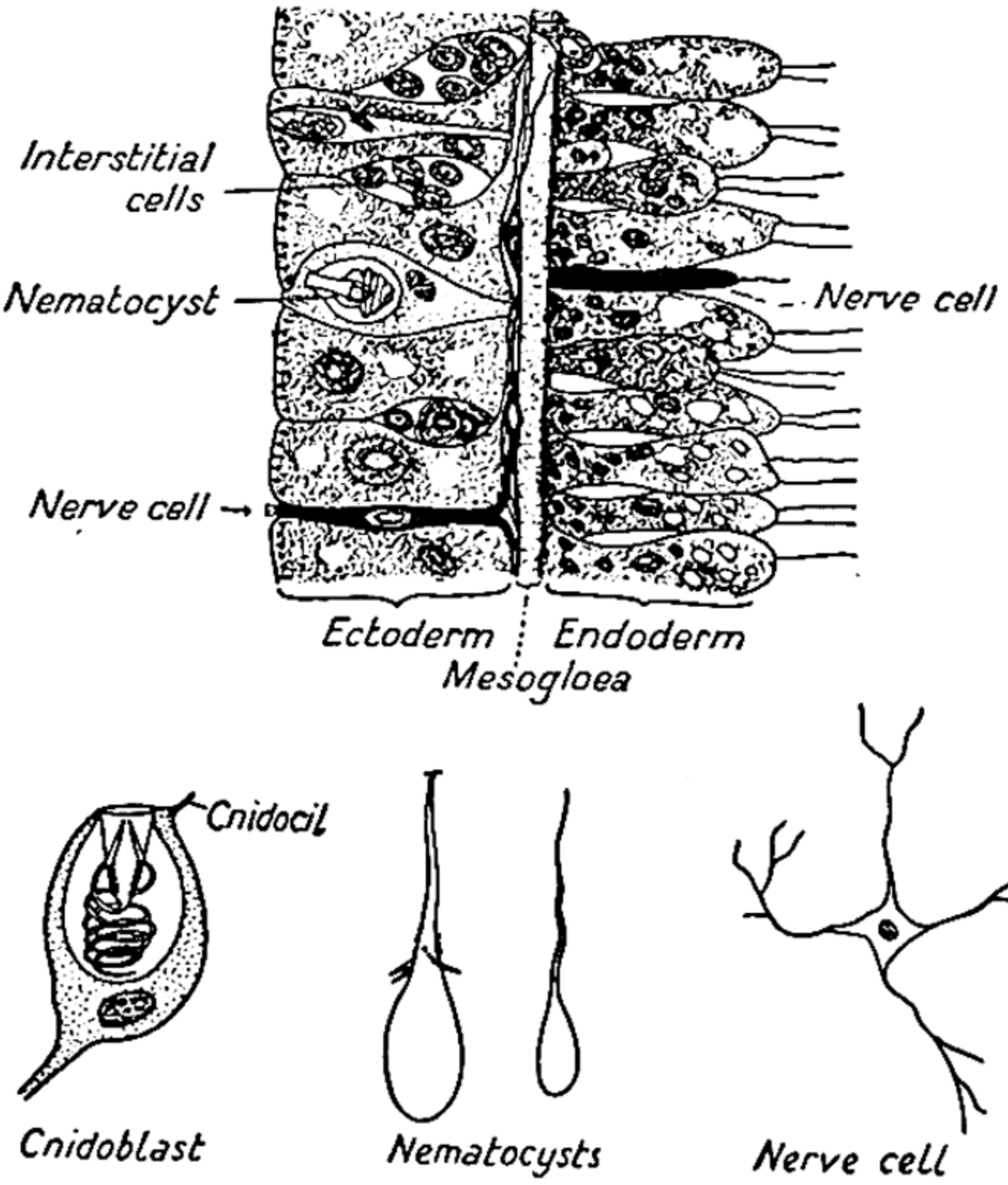


FIG. 33. Section of body-wall showing cells and tissues

stiff hair, the 'trigger' or cnidocil. This is a simple sense organ (cp. p. 229); when it is touched the whole cell contracts and its contained 'poisoned dart' or 'lasso' (nematocyst) is ejected.

(*c*) Nerve cells, whose processes are connected with the cnidoblasts.

(*d*) Small interstitial cells, which can give rise to new cnidoblasts, new ectoderm cells, &c. It is from these that the reproductive cells also arise (cp. p. 428).

The *endoderm* cells, which have large vacuoles, are also of more than one kind. They all have contractile processes which run round

the body; some are also secretory, producing digestive juices, others are 'phagocytes', that is, they can put out pseudopodia and ingest solid food. Many have flagella, which project into the gut cavity and help to keep the food in motion.

Between ectoderm and endoderm there is a layer of jelly, the *mesoglea*. In this, in addition to the muscle tails of the cells of ectoderm and endoderm, we find certain nerve cells, whose work it is to control the activities of the other parts of the body (cp. p. 209). Connected with these nerve cells there are certain sensory cells in both ectoderm and endoderm which seem to be specialized to receive stimuli. Finally this animal makes special male and female reproductive cells for the continuance of the species (cp. p. 429).

This process of differentiation and of specialization of parts of the body to carry on certain definite functions is carried to a much greater degree in the higher animals, as we shall see in our subsequent work.

THE HIGHER COELOMATE ANIMALS

DIGESTIVE ORGANS. The digestion of food within a gut cavity, which we discovered in Hydra, foreshadows the method of digestion found in the higher animals. In such animals the gut is usually a tube passing through the body from mouth to anus. As food passes along this tube, driven by successive contractions of its walls (peristaltic action), enzymes are poured on to it. When digested the food is absorbed and carried away to the various body cells, while any indigestible residue is expelled at the anus. The carrying of the absorbed food from one part of the body to another is one of the functions of the blood (cp. p. 306).

Digestive organs formed on this plan are found in all the higher invertebrates, such as worms, insects (e.g. cockroaches, butterflies, &c.), crayfish, lobsters, &c., as well as in all vertebrates. In the earthworm the alimentary canal is comparatively simple; let us now study its structure in more detail.

THE EARTHWORM.

External features and mode of life. Various species of earthworm are found widely distributed over the face of the earth, wherever the soil is not too dry. They live underground,

burrowing into the earth, often swallowing it as they go and passing it through their long, straight alimentary canal. They digest and absorb any organic matter it contains, using this as food, and deposit the residue as worm-casts. Worms have been working the soil in this way for millions of years, turning it over and breaking it up, bringing the deeper layers up to the surface, their burrows meanwhile allowing air and water to percolate downwards.

'The plough', said Charles Darwin in his book *Vegetable Mould and Earthworms*, which every biologist should read, 'is one of the most ancient and most valuable of man's inventions, but, long before he existed, the land was, in fact, regularly ploughed, and still continues to be ploughed by earthworms. It may be doubted whether there are many other animals which have played so important a part in the history of the world as have these lowly organized creatures.'

Experiment 63. To study the habits of earthworms we set up a 'wormery' in the following manner:

Obtain a large bell jar or a rectangular glass dish about 12 inches deep. Invert the bell jar, place a few pebbles at the bottom, and then fill it with layers of differently coloured, moistened earth. Garden soil, sand, and leaf-mould afford a good contrast. With a fine brush and white paint make lines on the glass to mark the divisions between the different layers of soil. Place several healthy worms in the 'home' thus prepared. Scatter a few leaf fragments, or minute cubes of such vegetables as onion, carrot, &c., on the surface of the soil. Cover the top with butter-muslin, and throw a black cloth over the whole.

Soon burrows will be made; some of these are sure to be against the glass, and their size and shape can be examined. Notice also how the worms treat the various fragments of food you leave on the surface. Experiment with different kinds. Keep the soil always slightly moist. Notice how the lower layers of soil are brought up to the surface, until, in time, the various layers are quite indistinguishable.

In nature these burrows end about 18 inches below the surface, though in cold weather they may penetrate to a depth of 6 or 7 feet. When conditions are unfavourable the worm often plugs the upper end of the burrow with leaves and other plant debris, or even with small stones. This gives protection from extremes of heat and cold, as well as from parasites and other enemies which may enter the burrow from above.

Exercise. Collect some worm castings, and notice how fine and powdery is the soil. Some of this soil is occasionally spread out by the worm to form a thin, smooth lining to the burrow. The animal smears it over the surface with its 'tail'.

External appearance.

Exercise. Examine an earthworm, and notice that its long, soft, slimy body is divided into rings, or segmented, there being about 150 of these segments. They closely resemble each other, this similarity indicating that the animal is a somewhat primitive one. The repetition of fundamentally similar parts, or *metameric segmentation*, is a marked feature in the structure of many animals, e.g. arthropods (cp. p. 155) and vertebrates (cp. p. 404), but in these higher forms the segments do not, as a rule, resemble each other so closely, but are more specialized and differentiated.

Observe that the worm has a definite head end, marked by a little solid prostomium, which projects in front of the first segment and overhangs the mouth, a small opening on the under (ventral) surface. From every segment of the body, except the first and last, there project four pairs of minute bristles or setae. These can be felt with the finger and observed with a lens. They are used in locomotion. Remove one of these structures from a dead worm and examine it under the microscope.

There is another opening, the anus, at the hinder end of the body. Mouth and anus mark the beginning and end of the alimentary canal. In the grooves between the segments are dorsal pores, tiny apertures which lead to the exterior. Various other apertures occur, chiefly reproductive; often there is a clitellum. These structures are all described on p. 497. One of the chief blood-vessels, the dorsal vessel, is visible through the body-wall. If we cut through this body-wall, which consists chiefly of muscle cells within a thin epidermis, the alimentary canal is at once seen.

Alimentary canal.

Exercise. Examine a dissection of an earthworm, opened to display the alimentary canal. This is a long, straight tube, running through the body cavity or coelom from mouth to anus, and supported by delicate transverse partitions (septa), which stretch across the coelom from the canal to the body-wall, in positions corresponding to the external furrows. Notice the blood-vessels on the wall of the canal.

We find that the body of the earthworm, like that of all the

higher animals, really consists of one tube, the gut, within a second tube, the body-wall. By this arrangement movements of the gut become independent of those of the body-wall, while undesirable substances (e.g. harmful bacteria) can be

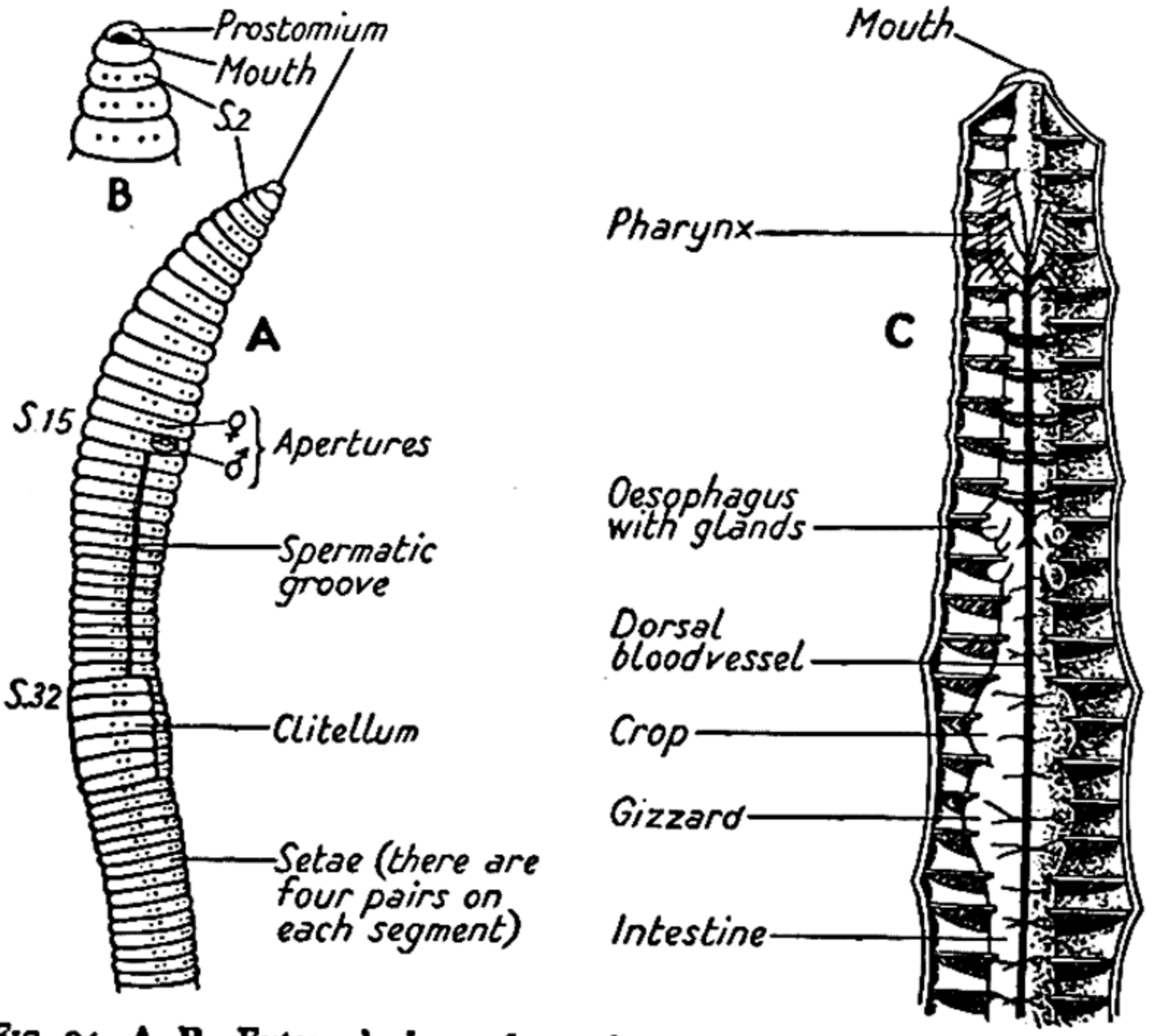


FIG. 34. A, B. External views of anterior portion of earthworm. C. The animal opened to show the anterior portion of the alimentary canal

dealt with in a digestive tube which is somewhat isolated from the rest of the body.

In the alimentary canal of the earthworm we may distinguish the following parts:

Mouth Muscular pharynx	Segments	1–6	Crop	Segments	13–16
			Gizzard	„	16–20
Oesophagus	„	6–13	Intestine	„	20–end.

Exercise. Draw the dissection to show these parts of the alimentary canal.

Food-getting and the processes of digestion. Worms live on leaves, such as those of cabbage and celery, and on the decaying organic matter (humus) in the soil. Food is grasped by a sucking action of the mouth and muscular pharynx. If the morsel is large it is first drawn into the burrow and covered with slime secreted by the gland cells of the skin; in this way it is moistened and possibly partially digested before it is taken into the body at all. From buccal cavity and pharynx the food passes into the narrow oesophagus. As it moves along this tube the acids contained in it are neutralized by a secretion containing calcium carbonate, poured into the oesophagus from certain glands and thickenings in the oesophageal wall (segments 11, 12, 13). (Cp. Fig. 34 C).

The food is temporarily stored in the thin-walled crop, and ground up finely in the strong, muscular gizzard. Thence it passes into the long intestine, where most of the digestion and absorption occurs. Enzymes are poured on to it from gland cells in the intestinal wall, and proteins are converted to amino-acids, starches to sugar, &c.; these soluble substances pass through the lining of the intestine into the thin-walled blood-vessels (capillaries with walls only one cell thick) which ramify in its wall. This wall is folded all along the dorsal surface; this fold, the typhlosole, considerably increases the area through which food may be absorbed.

The digested food is carried by the blood to all the cells of the body, providing them with materials for respiration, growth, and the repair of waste. The worthless residue passes on through the alimentary canal and is thrown out of the body at the anus, forming the 'worm-casts' already referred to.

Movements. With few exceptions, all animals must seek their food, depending on their own powers of locomotion to find it. A worm, for example, usually stays in its burrow by day, but leaves it at night for this purpose. Even then the 'tail' remains just inside the burrow, so that the worm can retreat at the slightest alarm. With its retreat thus secured, it moves its free 'mouth' end about in search of fallen leaves and similar nutriment.

These movements are due to contractions of the body-wall

Here there are definite muscle cells, arranged in two layers: an outer layer, in which the cells run round the body, and an inner one, in which they go down its length. Contractions of the former group make the body thinner and longer, while the latter group by contraction make it shorter and fatter.

A worm moves along by alternately shortening and lengthening its body. In order to move forward, for example, it grips the earth with the setae of its 'tail' end, elongating the rest of its body by contracting the circular muscles. Now it grips with the setae of the anterior end and, by contraction of its longitudinal muscles, draws up its 'tail'. It can move backwards as well as forwards, all such movements being caused by a similar use of setae and muscle cells.

ARTHROPODS. An earthworm is a segmented animal which shows a considerable amount of specialization between its cells and organs. The arthropods, or jointed-legged animals, form another group of segmented invertebrates which resemble earthworms in certain features of their structure. They are, however, on the whole, more highly organized than the worms. We turn now to examine a member of this great phylum, to which the crabs, crayfish, spiders, &c., as well as all the insects, belong.

INSECT STRUCTURE

THE COCKROACH. This animal, though it fills many of us with disgust, is nevertheless an interesting creature to study. Indeed, we are told that it makes:

'rather an interesting pet, as the creatures occasionally assume most comical attitudes, especially when cleaning their limbs. This they do somewhat after the fashion of cats.' (*Cambridge Natural History.*)

We are reminded of Aristotle's dictum:

'we must not recoil with childish aversion from the examination of the lower animals. Every realm of nature is marvellous.'

Live cockroaches are easily kept in a covered jam-jar; they can be fed on bread and water.

External features and mode of life. Two species of cockroach are very common in England, neither of them really British. One is the so-called black beetle (Blatta orientalis), which is

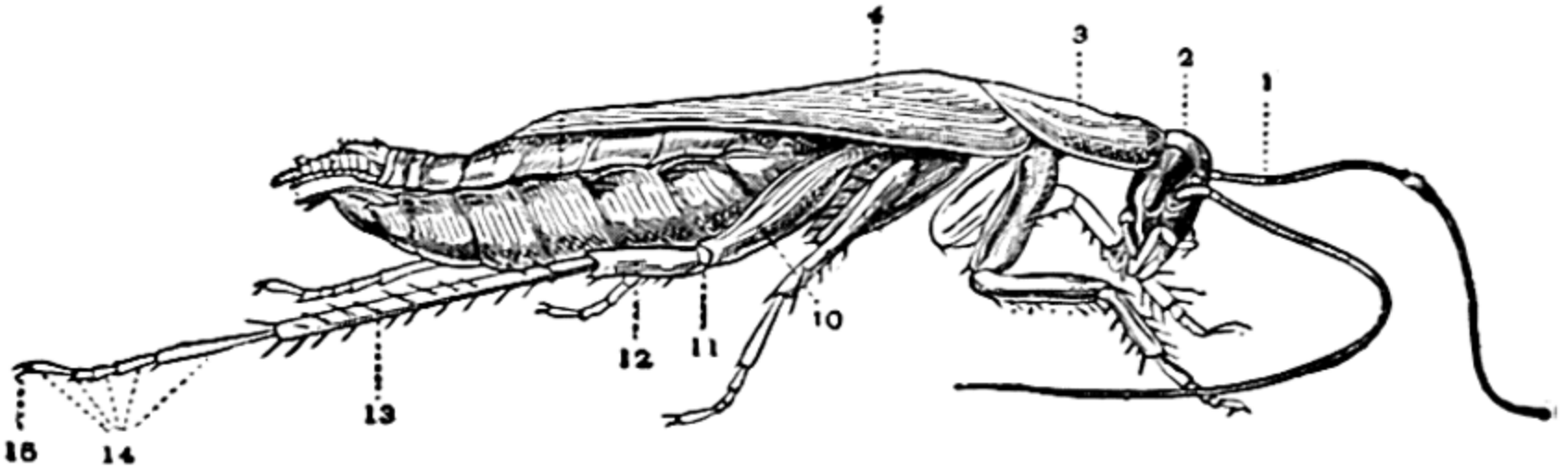


FIG. 35. SIDE VIEW OF MALE COCKROACH. 1. Antenna. 2. Head showing the large eyes. 3. First segment of thorax. 4. Wing. 10–14. The five main regions of the insect limb. 15. Claws

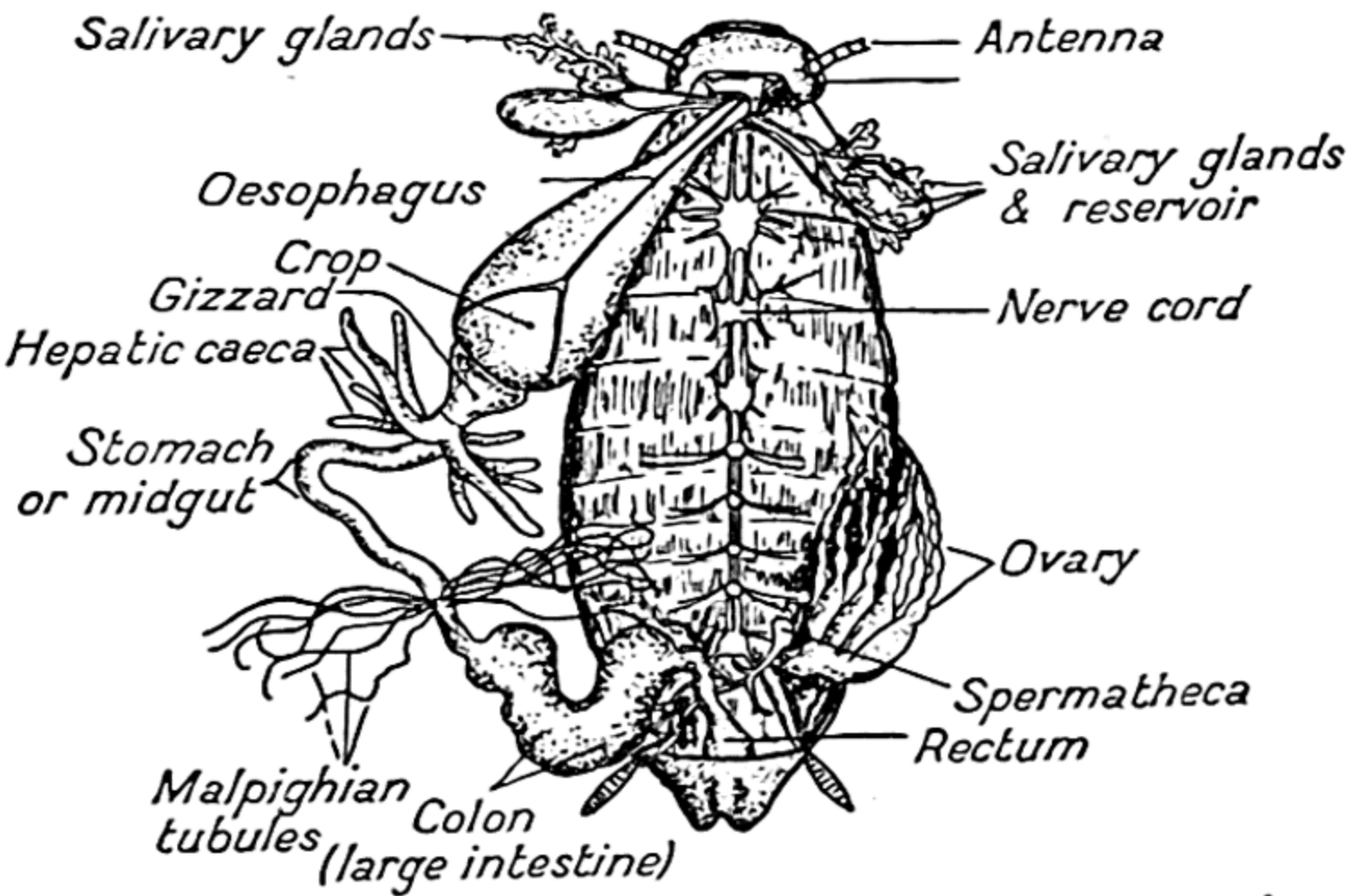


FIG. 36. A cockroach opened to show the alimentary canal and the nervous system

neither black nor a beetle; the other is the somewhat larger American cockroach (B. americana). Both these animals are almost 'domesticated'. The former infest buildings, especially underground kitchens, bakehouses, &c., while the latter are abundant in ships, dockyards, and similar haunts.

Exercise. Examine the external features of one of these animals and make sketches illustrating its structure. The body is obviously segmented and is covered by a hard, jointed external skeleton of chitin. It is divided into three parts, head, thorax, and abdomen. The thorax bears three pairs of jointed legs. All these features are very characteristic and are found in most insects (cp. Fig. 86).

Look at the *head*. It is bent forwards and hence almost concealed when we observe the insect from above. On it we notice the two large compound eyes, a pair of long flexible antennae, which are sensitive to touch and to smell (i.e. chemical stimuli), and the mouth, which you will find on the underneath or ventral surface. Round it are certain appendages (three pairs), which are modified to act as 'jaws'.

Now observe the *thorax*. This consists, as in all insects, of three segments. Each bears, ventrally, two strong jointed legs, consisting of five main joints. Sketch one of these legs. On the fourth and fifth joints there are the stiff bristles which the insect uses when cleaning itself, while the foot, or tarsus, is made up of five small segments and ends in two claws. Notice the special pad between the claws which assists the insect to climb vertical surfaces.

Most adult insects have wings, usually two pairs attached dorsally to the second and third thoracic segments (cp. Fig. 86). These two pairs are present in the American cockroach, but in the oriental species (black beetle) the female animals (which are black in colour) are wingless, while in the male (which is quite brown) the wings are very small (cp. Fig. 35 (4)).

Even the American cockroach is not a good flyer. Its anterior wings are horny and protective, only the posterior pair (find these) being membranous. When flying the horny wings are not moved, but are merely spread out and used as stabilizing planes.

The *abdomen* is flattened like the thorax, and consists of ten rather similar segments, most of which have no appendages. (Confirm this.) The anus opens on the tenth segment, and in both sexes we find here a pair of spindle-shaped outgrowths, while in the male we can recognize another pair of slender appendages, the so-called anal styles, on segment 9.

Alimentary canal. Broadly speaking this is a tube resembling that of the earthworm, passing through the body cavity or coelom, from mouth to anus. It is somewhat longer than the body and hence thrown into one or two coils. There is considerable division of labour between its parts. In a dissection

we recognize oesophagus, crop, and gizzard, as in the earthworm; but the hinder portion of the tube is more specialized, consisting of a definite mid-gut and a hind-gut, the latter being made up of the colon and rectum. (See Fig. 36, p. 156).

Further, there is, at the commencement of the mid-gut, a series of seven or eight 'blind' (i.e. with no opening at the farther end) tubular outgrowths, the hepatic caeca, which are perhaps best regarded as extensions of the mid-gut to increase the area of its digestive and absorptive surface (cp. typhlosole of earthworm).

At the junction of the mid- and hind-gut are a number of much finer outgrowths, the Malpighian tubules. These have nothing to do with digestion, but are excretory in function (Ch. XXVI).

Exercise. Examine a dissection of a cockroach in which the alimentary canal is displayed, and sketch it.

Food-getting and movement. Cockroaches are omnivorous feeders, eating both animal (e.g. meat, fish, leather, cheese, woollen cloth, and even the bodies of comrades) and vegetable food (e.g. paper, sugar, beer, &c.). They are nocturnal animals, lurking in dark crevices by day but coming out at night to feed. They are remarkably quick movers, running or scurrying away on their six legs when disturbed, their method of locomotion being very peculiar and characteristic. It must be observed in the living animal.

The processes of digestion. By means of the jaw-like appendages which surround the mouth, the food is grasped and torn apart. During this process it is moistened by a fluid secreted by the salivary glands. This fluid contains a carbohydrase, so that starch digestion begins outside the body. The food is now swallowed, passes down the gullet and into the extensible crop. Here the starch digestion already begun continues; fat is also digested by ferments secreted by cells in the walls of the crop, while a fluid containing proteases passes forward into the crop from lower down the canal and serves to begin the digestion of proteins.

The food is now moved on into the gizzard, whose function seems to be purely mechanical. It grinds and stirs up the food

and mixes it well with the enzymes of the various digestive juices. On its walls are six hard 'teeth' which assist in the process of grinding, while various bristles strain out any large fragments of food.

Owing to the effect of this strainer only fine particles are admitted to the mid-gut. Here a powerful digestive juice is poured on to the food; indeed, this animal can digest not only the usual food substances, carbohydrates, fats, and proteins, but even such 'indigestible' things as horn, hair, and wood. The processes of digestion and absorption are completed in the hepatic caeca, which are merely extensions of the alimentary canal. The indigestible residue passes on through colon and rectum, where water is probably absorbed and the faeces prepared for expulsion.

COMPARISON OF THE DIGESTIVE SYSTEMS OF HYDRA, EARTHWORM, AND COCKROACH. The alimentary canals of the earthworm and cockroach are both more highly developed than that of Hydra. We notice in particular:

1. The division of labour exhibited by the food canal, each part being specialized for some definite function in the whole work of digestion and absorption.

2. There is a posterior opening, the anus, which enables indigestible matter to be expelled after it has passed through the whole length of the tube.

3. There is a coelom separating gut from body-wall.

4. There is a blood-circulatory system in close connexion with the gut; this is specially well developed in the earthworm. It serves to distribute the absorbed food to all parts of the body.

All these features are possessed in a still higher degree by the vertebrate animals, to the study of whose digestive processes we may now turn.

QUESTIONS ON CHAPTER XIII

1. Describe the structure of a hydra; explain on what it lives, and how it captures and digests its food.

2. Describe, as far as possible from your own observations, the methods by which food is obtained by Amoeba and Hydra respectively. (C.L.)

3. How far can it be said that there is differentiation of parts or organs in Amoeba and Hydra? Compare these types in this respect. (C.L.)

4. Describe how Hydra can move from place to place, and how this animal captures and digests its food. (J.M.B.)

5. Give labelled sketches showing the structure of the alimentary canal of the earthworm, and give some account of the functions of its various parts. (C.W.B.)

6. Compare and contrast the 'gut' (food cavity) of Hydra and earthworm, and show why we call the latter 'more advanced' than the former.

7. In what way is Hydra more specialized than Amoeba? (Ox.L.)

8. Hydra is said to be a higher type of animal than Amoeba or Paramoecium. Explain what is meant by this statement and on what grounds it is based. (Ox. & C.)

9. Describe by what means you would attempt to discover what Amoeba, Hydra, cockroach, and the earthworm use for food.

10. What are the feeding habits of an earthworm, and what are the general effects of these habits on agriculture? (D.)

11. Make sketches of the alimentary canal and nervous system of the earthworm. Write notes upon the mode of life and economic importance of the animal. (C.W.B.)

12. Give an account of the external features and mode of life of an earthworm, and describe the part played by earthworms in the formation of the soil. (L.G.S.)

13. Give diagrams to show the external features of the earthworm, and name all the parts. Describe the mode of life of earthworms, the conditions under which they are likely to flourish, and the influence they exert over the vegetation in their immediate surroundings. (L.G.S.)

14. Give an account of the capture and digestion of food by either an insect (cockroach or grasshopper) or a crustacean (lobster or crayfish). (J.M.B.)

15. Describe as fully as you can how Amoeba and the earthworm move from place to place. How do these animals tide over the winter? (J.M.B.)

16. How do earthworms move about in the soil and above ground? How do they breathe? What do they eat and how do they take food into their bodies? (J.M.B.).

17. Describe the external parts of the cockroach, omitting details of the mouth parts. How does this animal breathe? (Ox.L.)

CHAPTER XIV

DIGESTIVE ORGANS AND DIGESTIVE PROCESSES IN VERTEBRATE ANIMALS

ORGANS OF DIGESTION IN VERTEBRATE ANIMALS. In all vertebrates the organs of digestion are formed on the same plan. The *alimentary canal* shows considerable division of labour between its parts, and is usually longer than the body, being thrown into loops and coils within the body cavity (*coelom*). It extends from the mouth, where the food enters, to the anus, where the indigestible residue is expelled, and consists of mouth, gullet or oesophagus, stomach, small intestine (the part adjoining the stomach being called the duodenum), and large intestine, the latter ending at the anus.

There are various *glands* in the walls of this canal, which discharge their secretions into it. Besides these scattered or diffuse glands, definite glandular organs pour in secretions by special ducts. These are the salivary glands, whose ducts open into the mouth, and the liver and pancreas, whose ducts open into the duodenum. (In the lower vertebrates there are no salivary glands.)

Although there are these broad similarities in the structure of the digestive apparatus, the details of structure vary between the different groups of vertebrates, and also with the kind of food consumed. Man is an omnivorous feeder, and can digest both animal and vegetable food (cp. p. 47). Let us begin our study of digestion in vertebrates with a description of the work done in our own alimentary canal, which in adults is from 27 to 30 feet long (cp. Figs. 4 and 42).

THE HUMAN ALIMENTARY CANAL

THE MOUTH. In the epithelium of the tongue there are taste organs (cp. p. 230) which guide us in the selection of suitable food. This is moistened by the saliva, which acts as a lubricant, and well subdivided by the teeth, so that a large surface is exposed to the action of the ptyalin (cp. exp. 55). So the

digestion of starch begins. The chewed food is rolled into a ball or *bolus* by the tongue, and 'swallowed', that is, passed into the upper portion of the oesophagus. Once there we cannot exert any conscious influence on its further progress.

Starch digestion, begun in the mouth, goes on for some time

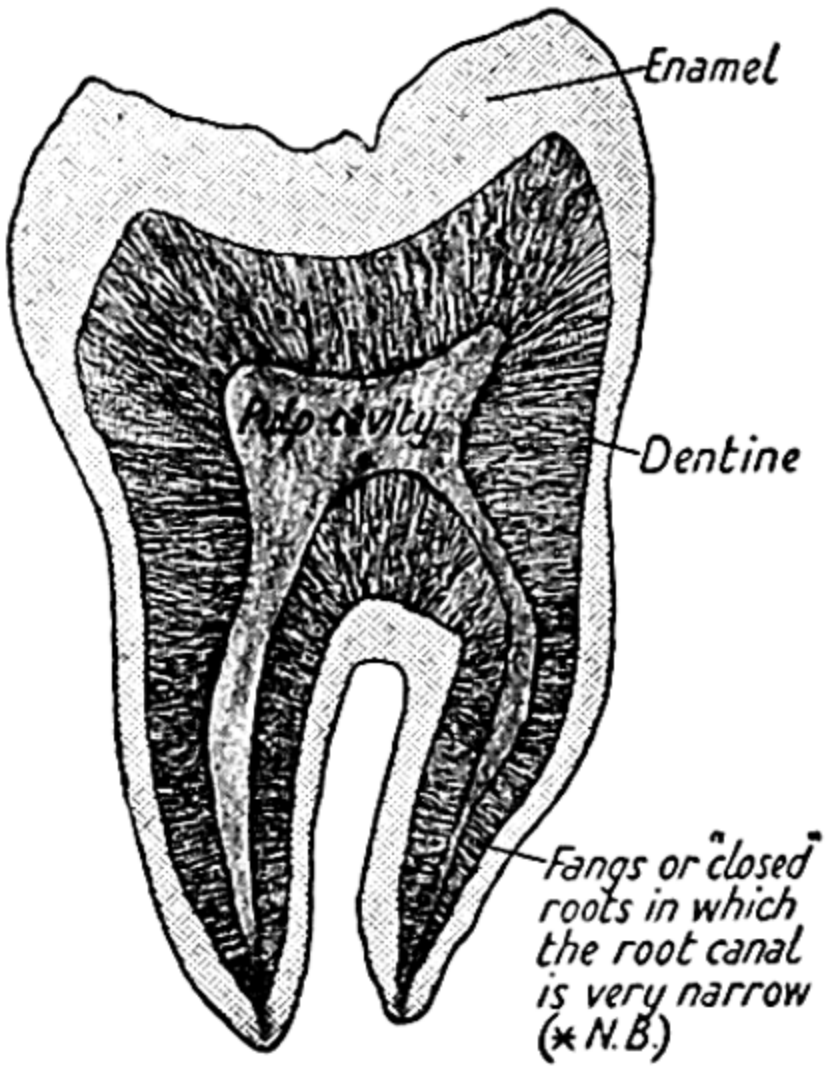


FIG. 37. SECTION OF A MOLAR TOOTH (HUMAN)

N.B. In a few mammals, some or even all (e.g. rabbit) of the roots remain permanently open, and the teeth can grow throughout life

after the food has reached the stomach; gradually, however, the gastric juice penetrates the bolus and, by its acidity (cp. p. 137, VI), inhibits the action of the ptyalin.

Teeth are bony structures, each consisting of a crown and one or more roots or fangs (cp. Fig. 37). The crown is formed of a hard substance called dentine, its exposed surface being still further hardened by a covering of enamel. In the centre is a pulp cavity containing blood-vessels and nerves. In mammals these teeth are always embedded in sockets in the jaw-bone, and the animal usually has two sets, a milk set in early life, which is gradually replaced by the permanent teeth.

We have 20 teeth in our first set, which vary in shape with the functions they perform. Thus we have:

8 *incisors* or cutting teeth, with sharp edges.

4 *canines* or flesh-tearing teeth, with more pointed edges.

8 *premolars* or double teeth, with flattened surfaces for grinding up the food.

The second teeth begin to replace this milk dentition in about the

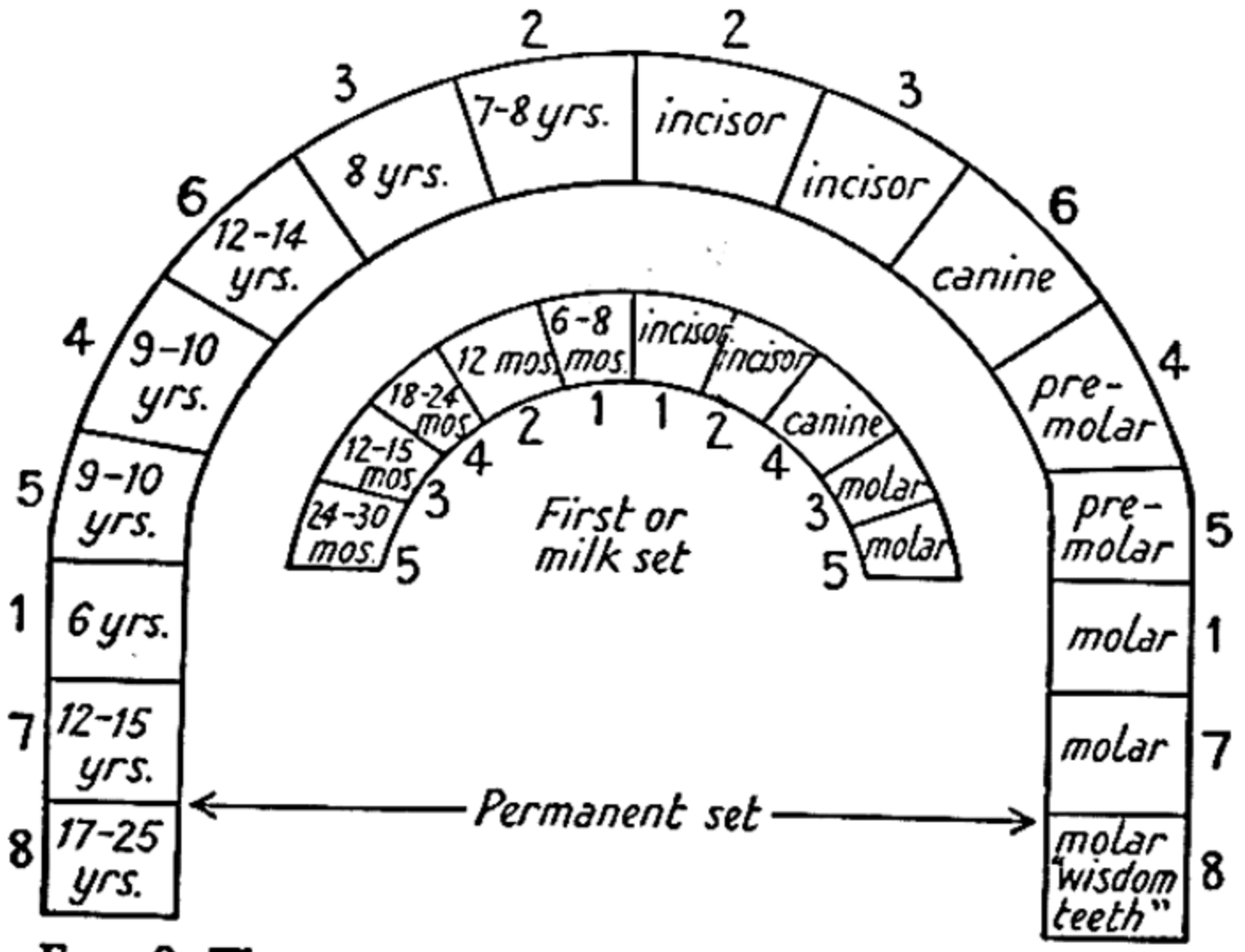


FIG. 38. The names and times of appearance, indicated by numbers, of both sets of teeth in man. (After Moon)

sixth year. The adult has 32 teeth, 8 incisors, 4 canines, and 8 premolars, which replace milk teeth, and 12 *molars*, which appear in the permanent set only. This is nearly always complete by the 25th year (cp. Fig. 38).

Dental formulae. Mammals usually show some division of labour between the teeth, accompanied by a corresponding variation in their form. The number of the different kinds of teeth possessed by any animal can be expressed by a dental formula, which shows the various types present in each half-jaw. The dental formula for man is:

$$\text{I. } \tfrac{2}{2}.\ \text{C. } \tfrac{1}{1}.\ \text{Pm. } \tfrac{2}{2}.\ \text{M. } \tfrac{3}{3}.\qquad \text{Total } 32.$$

Exercise. Look at the skulls of the dog, cat, tiger, &c., and contrast the teeth with those of the horse, sheep, and rabbit. The former are flesh-eaters, the latter herbivores. Sketch the upper and lower

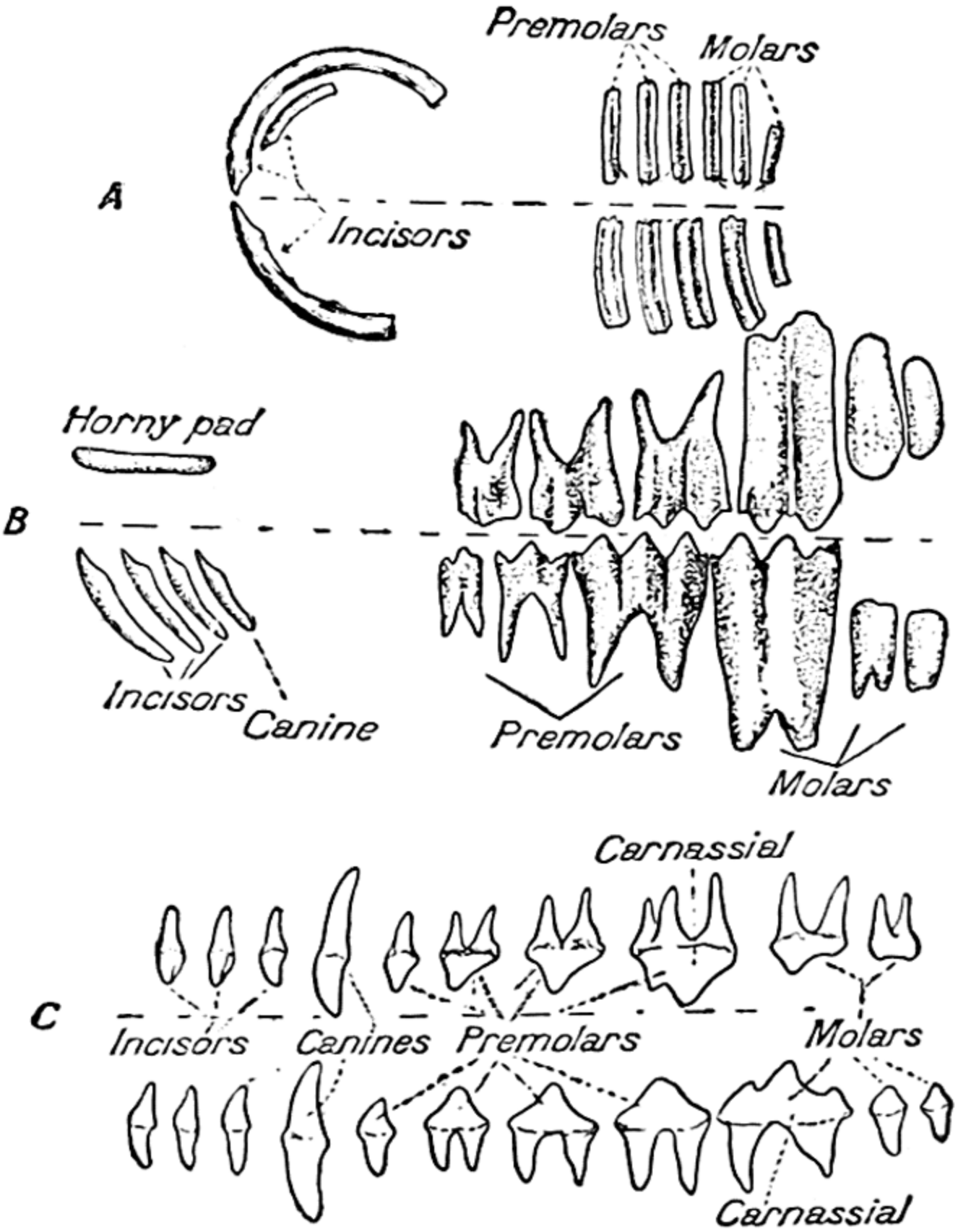


FIG. 39. **A.** Teeth of rabbit; **B,** of sheep—both herbivorous animals. **C.** Teeth of dog—a carnivorous animal

jaws of the dog and rabbit to illustrate the form and arrangement of the teeth and write the dental formulae.

Exercise. Examine and sketch the jaws of the frog skull in the same way, paying special attention to the teeth.

SWALLOWING THE FOOD. The mouth narrows into the 'throat'

(*pharynx*). In man there are six openings into this part of the canal (cp. Fig. 43), two from the nose, two from the ears, and the openings of oesophagus (gullet) and rachea (wind-pipe) respectively. As it is swallowed, the food must be passed over the opening of the latter, and directed into the oesophagus (cp. Fig. 4). Breathing ceases momentarily, and the opening into the larynx (top of wind-pipe) is protected:

(1) By the bringing down over it of the epiglottis, a flap of cartilage.

(2) By the drawing together of the vocal cords.

In this way the food enters the oesophagus, and there is no danger of its passing into the trachea. We see that many different movements must be co-ordinated for this purpose. The method of co-ordination will be discussed in a subsequent chapter. (Cp. Chapter XVIII.)

THE OESOPHAGUS. The muscles at the top of the oesophagus now close round the food bolus; each portion of the tube relaxes to receive it, and then contracts to drive it on. By these successive relaxations followed by contractions (peristaltic action) the bolus is propelled through the oesophagus, which is about 10 inches long (cp. Fig. 4). It takes 5 or 6 seconds to reach the lower end of this tube, and from there it trickles more slowly into the stomach.

THE STOMACH. This is a large bag, capable when distended of holding about 4 pints of fluid. It lies just beneath the diaphragm on the left side of the abdominal cavity, and partly covered by the liver (cp. Figs. 3, 4). This, the largest organ in the body, and weighing about 53 oz., lies immediately beneath the diaphragm, chiefly on the right.

Digestion in the stomach. The food remains in the stomach for 2 or 3 hours, and here active digestion begins. It is kept in motion by peristaltic movement of the stomach walls, waves of contraction following each other at intervals of about 20 seconds. At the same time it becomes mixed with gastric juice, a colourless slightly acid fluid (cp. p. 169), containing two proteases, which begin to break up the proteins into peptones and proteoses (nitrogenous compounds more soluble than proteins and whose molecules are considerably smaller; cp. p. 140).

This gastric juice is produced by simple tubular glands in the stomach wall. Their openings are visible with a lens as tiny pores in the lining layer of mucous membrane.

Two or three hours after it enters, the food in the stomach has been reduced to a pulpy, almost fluid condition (chyme). There is a round 'sphincter' muscle at the junction of stomach and small intestine. When the food is ready this relaxes and permits a small amount of chyme to escape. In this manner the stomach is gradually emptied.

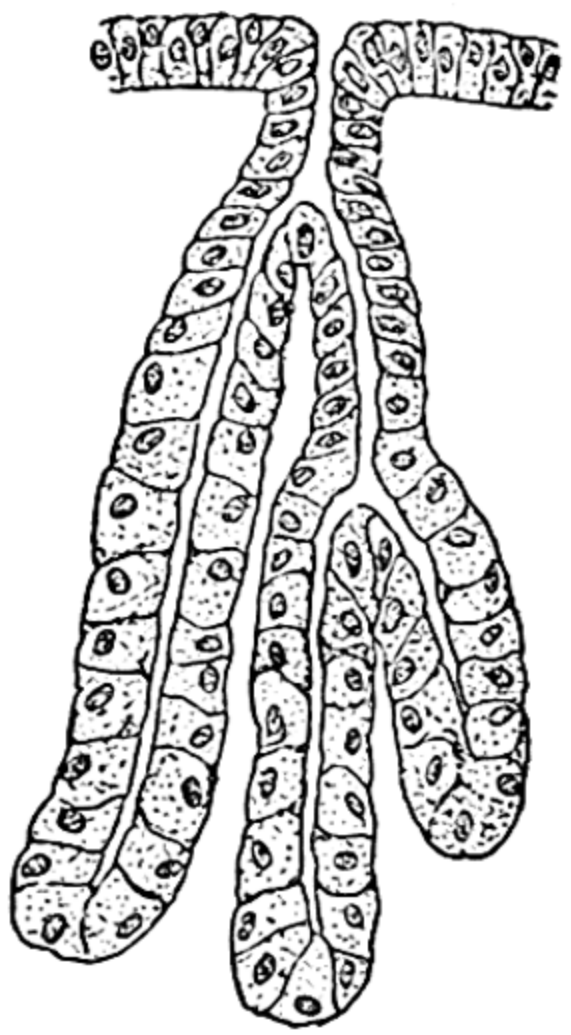


FIG. 40. A gland from the wall of the frog's stomach

Exercise. Examine the inner surface of a pig's stomach with a lens, and notice the numerous little pits. These are the openings of gastric glands.

THE SMALL INTESTINE. The human small intestine is a narrow tube about 18 feet long. (N.B. In Fig. 42 this is much shortened for clearness.) Here digestion is completed and the food is actively absorbed. Digestion is brought about by three juices: (i) the pancreatic juice, (ii) the bile, (iii) the intestinal juice or succus entericus.

The *pancreas* is a small creamish-coloured organ which lies between the stomach and the first loop (duodenum) of the intestine (cp. Fig. 42). Its secretion, the strongly alkaline pancreatic juice, contains several enzymes, so that every class of food—protein, carbohydrate, and fat—is affected.

The *liver*, among its many other functions (cp. p. 171), secretes bile, a golden-yellow alkaline fluid. In man the bile-duct from the liver joins the pancreatic duct, and the two open together into the upper part of the duodenum, about 3 inches behind the pylorus (cp. Fig. 42).

The third juice of the intestine, the intestinal juice or succus entericus, is secreted by the walls of the tube itself. These walls are thrown into folds, like the folds on corrugated

cardboard (cp. Fig. 41 A), and the whole of the mucous membrane which lines the tube is raised into numberless minute processes, the villi (cp. Fig. 41 B). These are just visible to the naked eye, and impart a velvety appearance to the whole internal surface.

In this mucous membrane are numerous simple glands,

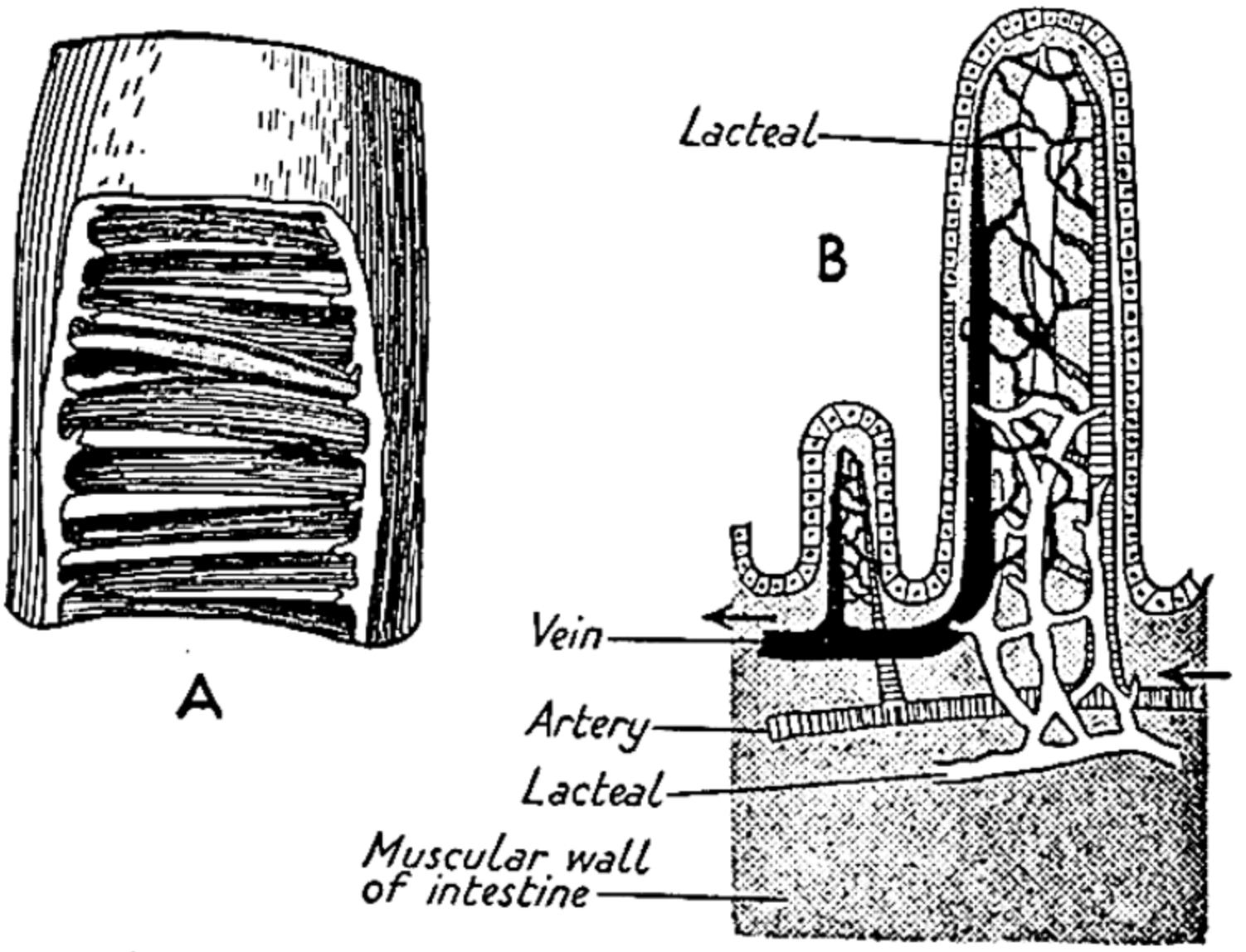


FIG. 41. **A.** Portion of human small intestine cut open to show the transverse corrugations. **B.** A villus, very highly magnified, to show the blood capillaries and lacteals

whose minute circular openings can be seen with a lens as tiny dots at the base of the villi. These are the glands which secrete intestinal juice.

All these secretions complete the process of digestion, of which further details are given in the tables on pages 168 and 169. The first table summarizes the changes which the food undergoes as it passes through the alimentary canal, while the second shows the action of the various digestive juices.

A consideration of these tables shows how, step by step, our food is digested and prepared for absorption.

TABLE. CHANGES WHICH FOOD UNDERGOES WHILE PASSING THROUGH THE ALIMENTARY CANAL

Organ	*Chief structures aiding digestion*	*Summary of the work done*
Mouth	Teeth	Food is ground up and subdivided
	Taste buds	These guide in the choice of food
	Salivary glands secreting saliva	Moistens food and begins digestion of starch
	Tongue	Rolls food into ball preparatory to swallowing
Oesophagus	Muscular walls and mucous glands	Contract and drive food into stomach, lubricate the food
Stomach	Muscular walls	Keep food moving and churn it up
	Gastric glands	Pour on to food gastric juice, which moistens it further and promotes digestion
Pancreas	Secretory cells of pancreas	All pour their respective digestive juices on to the food as it passes through the small intestine (see table following); food is made still more liquid and digestion is completed
Liver	Secretory cells of liver	
Small intestine	Secretory cells of glands in intestinal wall	
Lower portion of small intestine	Villi on walls (cp. Fig. 41)	Digestion completed, and digested food is absorbed
Colon	Walls of colon	Water absorbed and waste products discharged into cavity of canal
Rectum	Muscular walls	Waste matter (faeces) expelled

TABLE. THE ACTION OF VARIOUS DIGESTIVE JUICES

Juice	*Where formed*	*Composition*	*Action*
Saliva	Salivary glands opening into mouth	Mucin PTYALIN, a carbohydrase	Moistens and lubricates food Starch→maltose (a disaccharide)
Gastric juice	Glands in stomach wall	0·02 per cent. hydrochloric acid PEPSIN, RENNIN } proteases	Paves way for action of pepsin, which requires an acid medium Proteins→peptones Clots proteins of milk
Pancreatic juice	Certain cells of the pancreas	Sodium carbonate (trace) AMYLOPSIN, MALTASE } carbohydrases TRYPSINOGEN, converted to TRYPSIN, a protease, by Enterokinase (see below) LIPASE	Paves way for action of various ferments which require an alkaline medium Starch→maltose Maltose→glucose Proteins→amino-acids Fats→glycerol and fatty acids
Bile	Liver cells	Various bile salts, &c.	Aids digestion of fats
Intestinal juice (succus entericus)	Glands in wall of small intestine	MALTASE, INVERTASE, LACTASE } carbohydrases	Maltose (disaccharide) →glucose (monosaccharide) Sucrose (disaccharide) (cane sugar)→various monosaccharides Lactose (disaccharide) (milk sugar)→various monosaccharides
		EREPSIN, ENTEROKINASE } proteases	Proteoses and peptones →amino-acids Trypsinogen→trypsin

Proteins are converted to *amino-acids* by the enzymes pepsin, trypsin, and erepsin. *Carbohydrates* to one or other of the *simple monosaccharide sugars* by the enzymes ptyalin, amylopsin, maltase, invertase, and lactase, each of these causing one specific change. *Oils* are reduced to *glycerol* and *fatty acids* by lipase, aided by the bile.

ABSORPTION OF THE DIGESTED FOOD. The food, having thus been broken up into soluble and diffusible substances, is ready to be absorbed. This occurs mainly in the small intestine, particularly in the ileum, which, because of its length, its corrugations, and its villi, exposes a very large surface to the food.

Each villus contains a network of capillary blood-vessels, and one or more fine tubes known as lacteals (cp. Fig. 41). Amino-acids and sugars pass into the blood capillaries, fats very largely into the lacteals.

While these products of digestion are being absorbed by the columnar cells which line the wall of the small intestine, they undergo certain changes. Some of the amino-acids pass into the blood unaltered, and are dealt with in the liver; others are probably converted into actual blood proteins, albumin and globulin, by the absorbing cells. Similarly, these cells cause the glycerol and fatty acids to recombine, so that fat is once more formed.

Hence we see that this process of absorption is not one of simple diffusion or osmosis, but that it depends, too, on the activity of the living cells of the intestinal wall; further, there is a certain amount of assimilation of the products of digestion directly they pass out of the gut and into the cells of the body.

Most of the absorbed food, however, is carried by the portal[1] vein (cp. Fig. 90) to the liver, and we shall see later what happens to it there.

THE LARGE INTESTINE. From the small intestine the residue of the food moves on into the large intestine, which consists in man of the colon and rectum. As it passes along the colon

[1] The capillaries of stomach and intestine unite into small veins which eventually join to form the portal vein.

water is absorbed, so that it becomes more and more solid. At the same time waste products are added to it by the colon walls, and this mixture of excretory products and indigestible matter (the faeces) passes into the rectum. It is now ready for expulsion. The long processes of digestion and absorption, which have taken perhaps 48 hours to complete, are ended.

THE FUNCTIONS OF THE LIVER. The liver is a large glandular organ which is the general chemical laboratory of the body. It has many functions:

(*a*) In the liver cells the sugar absorbed from the gut is converted to *glycogen* (animal starch) for temporary storage. After a heavy meal, the cells are full of glycogen granules; but they are empty after some hours of active exercise. It is from this store that the tissues are supplied with sugar in quantities to meet their varying needs, the conversion of glycogen to glucose keeping pace with the demands of the body cells for sugar; this demand always increases as the activity of the body increases.

(*b*) The liver also deals with the *amino-acids* absorbed from the gut, passing these on to the tissues if they are required; otherwise preparing them for excretion, as explained below.

(*c*) The liver also plays a part in *fat metabolism*. If its glycogen store is used up, as after heavy exercise or during starvation, it can then draw on the fat deposits of the body, converting this stored fat to carbohydrate. Conversely, if the diet supplies carbohydrate in excess of the body's immediate needs, the liver may convert this excess to fat, which is sent to the 'fat depots' for more permanent storage (cp. Fig. 104). You have only to look at the 'Christmas beef' as it hangs in the butcher's shop to realize how much fat may be stored in this way. There are masses of it under the skin, round the abdominal organs, and even round the heart.

(*d*) In addition to all these feeding and food-storing activities, the liver also deals with all *waste nitrogen*, whether this comes from the food or arises from the activities of the tissues. Such waste is converted by the liver cells to urea ($CO(NH_2)_2$), a very

soluble substance which is afterwards excreted by the kidneys (cp. Chapter XXVI).

(*e*) The liver also deals with any *poisonous substances* which may pass into the blood from the intestine, e.g. with ammonia, large amounts of which are set free in the processes of digestion and absorption of protein food. It brings about chemical changes which render such substances harmless.

'The liver is therefore the true guardian of the organism, which changes the poisonous substances coming from the alimentary canal into harmless ones.' (Pavlov.)

(*f*) Finally, the liver forms *bile*, which is partly a digestive juice (cp. p. 169), partly an excretory product. The bile is stored in the gall-bladder.

As the result of these manifold activities, the liver plays a very important part in regulating the composition of the blood. It stores food temporarily, and passes it into the blood as required.

THE RABBIT, AN HERBIVOROUS MAMMAL

ALIMENTARY TRACT. The rabbit is an herbivorous mammal, man is omnivorous. In the rabbit, as in man, the alimentary canal consists of mouth, oesophagus, stomach, small intestine, and large intestine, opening to the exterior at the anus (cp. Fig. 3). The rabbit possesses in addition a large blind diverticulum (cp. Fig. 42), the caecum, at the junction of small and large intestine. We shall consider its function later.

The mouth of the rabbit differs in several respects from that of man, being adapted to deal with tougher food. It is bounded by furry lips, and at each side there is a gap, devoid of teeth, called the diastema. Grass, &c., bitten off by the sharp front teeth can be rolled and sucked into the mouth through these openings.

The teeth are of two kinds only (cp. Fig. 39), incisors and grinding teeth (premolars and molars). Between the two types lies the diastema. The dental formula is:

$$\text{I. } \tfrac{2}{1}. \quad \text{C. } \tfrac{0}{0}. \quad \text{Pm. } \tfrac{3}{2}. \quad \text{M. } \tfrac{3}{3}. \qquad \text{Total 28.}$$

The four incisors of the upper jaw are arranged in two pairs,

two large ones in front, and two small ones directly behind these. They meet the two incisors of the lower jaw, and together form an excellent cutting surface for tough food. These incisors grow throughout life, new material being formed in the gum as the teeth are worn away below. The enamel is practically confined to the front of these teeth (cp. Fig. 37); being much harder than the dentine it wears away more slowly, and in this manner a sharp chisel-like edge is maintained on each incisor, making these teeth very suitable for biting off grass, &c. The premolars and molars have flat, grinding surfaces, marked by ridges and grooves, which enable the animal to grind up its vegetable food. There are no canines, canine teeth being specially adapted for tearing flesh.

The roof of the rabbit's mouth is ridged and the surface of its tongue hard; these structures help in the breaking up of tough food. The rabbit can also move his jaw backwards and forwards in a way impossible for a human being. This again facilitates the grinding up of hard food.

The functions of the mouth are similar in the two animals, and the rabbit has four pairs of salivary glands.

From the mouth food goes along the oesophagus, a narrow muscular tube which passes through the thorax beneath the backbone, pierces the diaphragm, and opens into the stomach. This is a wide sac-like structure lying immediately beneath the diaphragm, chiefly on the left side. From it partly digested food passes on into the small intestine, a narrow tube about 8 feet long and less than 1 inch in diameter. The first part of this tube, known as the duodenum, forms a long U-shaped loop, between the two arms of which the pancreas lies.

This organ is not solid in the rabbit, but consists of scattered masses of glandular tissue. The pancreatic duct runs backwards, receiving small ducts from the various scattered portions of the gland, to open into the further (distal) arm of the duodenum about 3 inches beyond the bend (cp. Fig. 42 B).

The large intestine consists of the colon, about 1½ feet long, and the rectum, about 2½ feet long. The walls of the colon are puckered (sacculated) in a characteristic manner (cp. Fig. 41). Faecal pellets are usually visible in the rectum.

THE CAECUM. At the junction of small and large intestine is the caecum, a large, blind tube nearly 2 feet long, and much wider than the other parts of the intestine (cp. Figs. 3, 42); it ends in a narrow, thick-walled vermiform appendix, about 4 inches long. This caecum is connected with the digestion of cellulose. There is a small unimportant caecum and a vestigial appendix in man (cp. Fig. 42 A). The reader should remember that human beings cannot digest cellulose (cp. p. 175).

THE LIVER of the rabbit consists of five lobes, from each of which a duct arises. These join to form the bile-duct, which opens into the duodenum a short distance behind the pylorus. These two ducts are therefore separate in the rabbit (cp. Figs. 42 A and B). There is a gall-bladder for storing bile, opening out of the bile-duct.

Exercises

Examine the head of a living rabbit: notice its eyes, ears, nostrils, mouth, &c., and closely observe its method of dealing with food.

Examine the skull of a rabbit: remind yourself of the structure of the teeth and of the dental formula; then examine the joint between the upper and lower jaw, and try to discover what motion is possible.

Examine a dissection of a rabbit, opened to display the alimentary canal.

Examine and sketch the alimentary canal of the rabbit, which has been removed from the animal and spread out on a dissecting board.

Examine a dissection made to display the liver and portal vein of the rabbit.

COMPARISON OF THE ALIMENTARY CANAL OF MAN AND RABBIT. Comparing the alimentary tract of man and the rabbit, we find many striking resemblances between the two. Both are formed on the same plan, and the digestive processes are similar in the two. The differences observed are chiefly such as are necessary to enable the animals to deal with different foods.

Tongue, teeth, &c., are, as we have seen, different in the two. In man the intestine is about 25 feet long; in the rabbit its length, including that of the caecum, is about 14 feet. Yet a man weighs at least thirty times as much as a rabbit.

Obviously the alimentary canal of the rabbit is very much longer in comparison with the animal's size.

FUNCTION OF CAECUM. We always find that herbivorous animals have a longer and more complicated digestive tract than carnivorous ones. Vegetable food is more bulky than

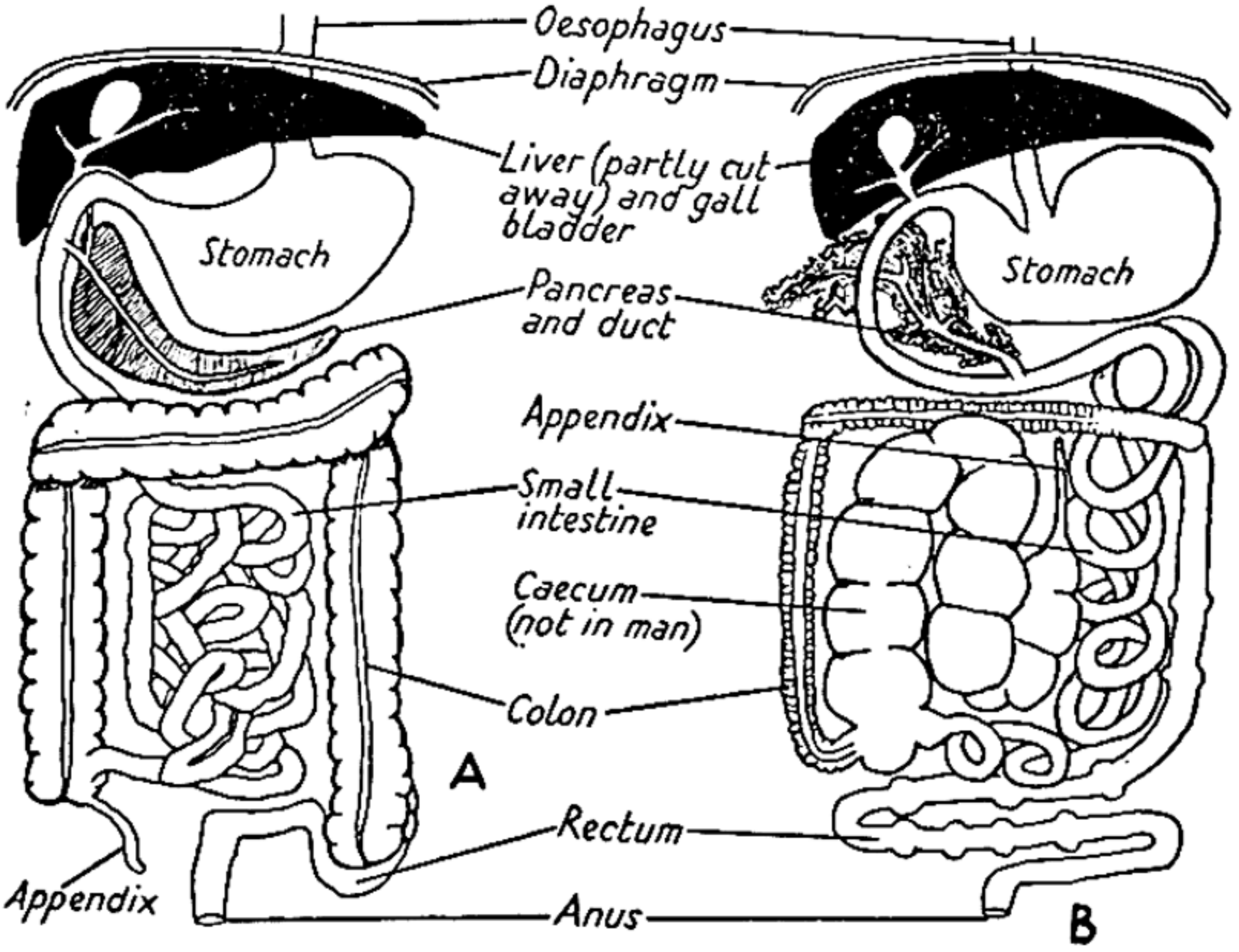


FIG. 42. Alimentary canal of man (**A**), rabbit (**B**) (diagrammatic)

animal food; far more must be eaten to furnish the same amount of nourishment. The alimentary canal of the herbivorous tadpole is longer, for example, than that of the flesh-eating frog. The canal actually becomes shorter at metamorphosis. Many herbivores have several 'stomachs'; the cow possesses four.

Further, vegetable food consists largely of cellulose, and no vertebrate animals form a cytase, i.e. an enzyme for its digestion. They rely on the secretions of bacteria living in the gut. The caecum of the rabbit is an organ into which the food is, so to say, side-tracked for a time, so that it can undergo

bacterial digestion. Man has only a vestigial caecum, and cannot digest cellulose at all.

This comparison of man and rabbit has served to illustrate two important facts:

1. The fundamental similarity of the digestive tract in all mammals.
2. The adaptation of the organs of each animal to its own special food.

THE ALIMENTARY CANAL OF THE FROG

Let us now examine the frog as an example of a vertebrate animal belonging to a lower group.

THE MOUTH (cp. Fig. 43). The frog possesses both teeth and a tongue. The teeth are small and are all similar in shape. They are not embedded in bony sockets and are formed on the upper jaw only, where they not only edge the jaw-bone, but also occur in two patches, the vomerine teeth, on the roof of the mouth. These teeth are not used to tear up food, but are helpful in the capture of prey.

On the roof the eyes are obvious, and they can actually be pressed down into the mouth cavity to aid in the capture of food. There is no hard palate to separate the nasal passages from the mouth, as in mammals (cp. p. 164) and the internal nares open into the front of the mouth.

The sticky muscular tongue is attached by its front end, the hinder end being free. It can be flicked out and used for the capture of the worms, slugs, small insects, &c., on which the frog feeds. He will not attempt to catch 'food' unless it is moving, a fact which makes live frogs somewhat difficult to keep in the laboratory. The frog has no salivary glands, only mucous-secreting ones.

At the back the mouth passes into the pharynx. Here we observe the glottis, a narrow slit-like opening in its floor which leads into the short bronchus (cp. Fig. 43). These structures are connected with respiration.

The pharynx narrows into the oesophagus, which passes into the sac-like stomach. There is no diaphragm in the frog,

separating the coelom into thorax and abdomen, and the oesophagus is very short.

From the stomach the food passes into the small intestine.

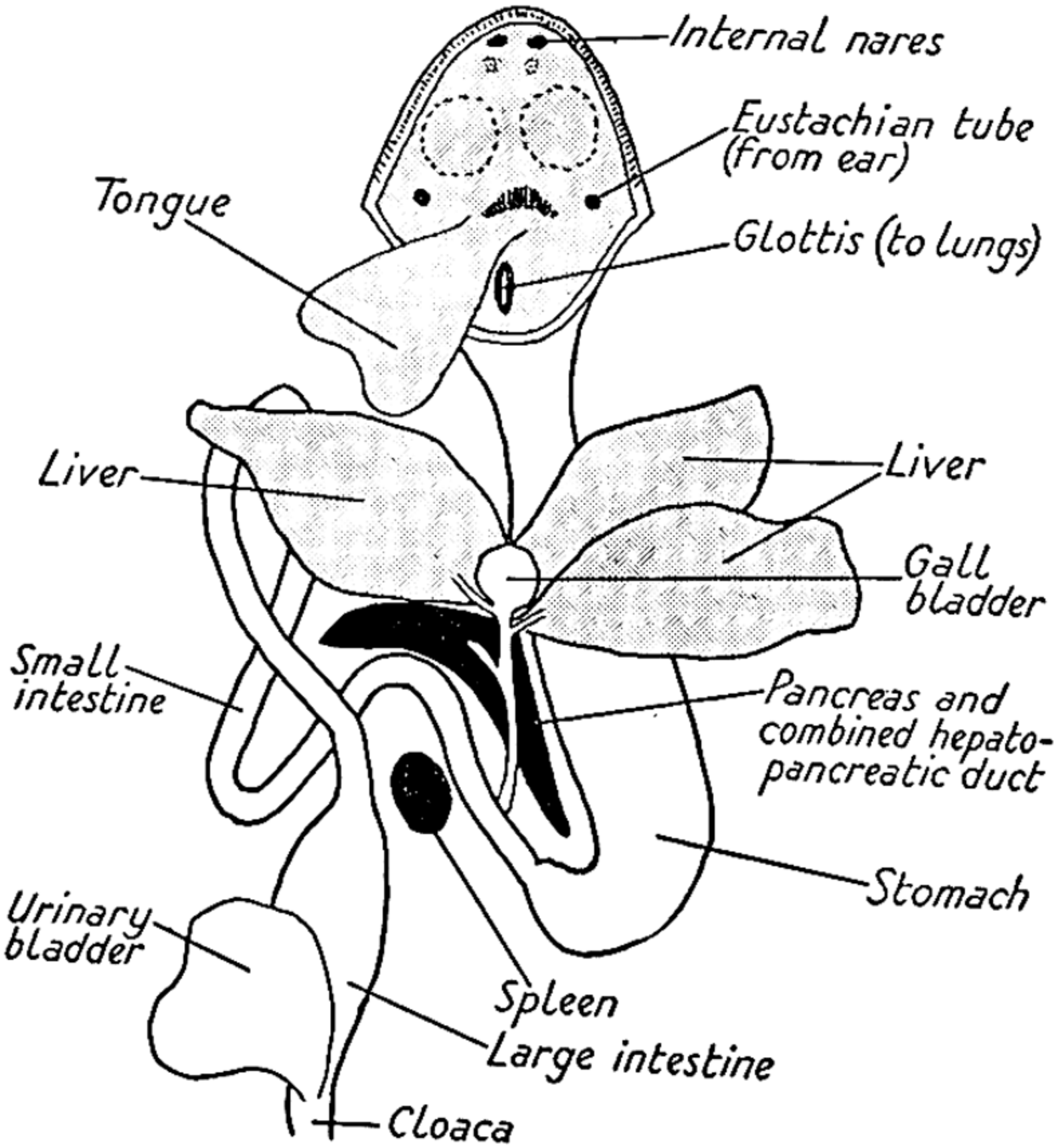


FIG. 43. Alimentary canal of frog (diagrammatic)

This is comparatively short—only 4 or 5 inches long—and is thrown into two or three loops only.

There is a bile-duct from the liver into which the pancreatic duct opens, and the common duct from the two opens into the beginning of the intestine.

The small intestine passes directly into the large intestine,

which consists of rectum only. This opens into the cloaca, and not directly to the exterior (cp. p. 430). Digestion and assimilation take place in the frog as in the other vertebrates we have studied, and most of the absorbed food is carried by the hepatic portal vein to the liver (cp. Fig. 100).

Exercises

Examine a dissection of a frog, opened to display the alimentary canal. Make sketches to show the structure; also a sketch of the liver, gall-bladder, and portal vein.

Examine a prepared transverse section of the small intestine of the frog, which has been stained and mounted. Notice the folds on the inner intestinal wall.

Examine and sketch the mouth of a frog, opened to display the tongue, teeth, eyeballs, internal nares, oesophagus, and glottis.

QUESTIONS ON CHAPTER XIV

1. Say what you know of the structure and functions of teeth. Describe in detail the differences between the teeth of any mammal with which you are familiar, and give the dental formula. Your answer should be illustrated by sketches. (C.L.)

2. Describe the teeth of a rabbit, or other mammal, with reference to their function. (C.L.)

3. Give an account of the structure of mammalian teeth and indicate how the structure of a tooth is related to the function which it performs. (Ox. & C.)

4. Give an account of the structure and functions of (*a*) the stomach, and (*b*) the small intestine, of the rabbit or other mammal.

5. What do you understand by digestion? Describe the alimentary canal of the rabbit or frog, and briefly outline the functions of its various parts.

6. A dog is given a meal of meat (with fat) and biscuit. Describe what happens to the chief constituents of this food as it passes down the alimentary canal from the mouth to the intestine. (J.M.B.)

7. Give an account of the appearance and external structure of the liver in either the rabbit or the frog, so far as these can be determined by the naked eye; enumerate and briefly describe the chief functions of this organ.

8. Give an account of the process of digestion and assimilation of food in a vertebrate animal. (Ox. & C.)

9. What do you mean by absorption of food? Show how the structure of the small intestine fits it to perform this task, and say what you know of the fate of the absorbed food.

10. Write a short essay on the storage of reserve food in the body of a vertebrate animal, describing as fully as you can the subsequent fate of the food so stored.

11. Of what does the food of a frog consist? How does it obtain this and digest it? Include in your answer a brief description of the structures concerned in the processes named. (C.W.B.)

12. What are the main blends of substances made use of by animals as food? Describe how a mammal digests any one of these. (B.)

13. Explain what is meant by digestion, and give a brief account of the organs concerned in this process in any vertebrate type you have studied. (C.W.B.)

14. Describe the process of digestion in a mammal. What are enzymes, and what part do they take in digestion? (L.G.S.)

15. Write an illustrated account of the alimentary canal in the frog, and describe the process of digestion in this animal. (O.L.)

16. Compare the chemical changes that take place in the alimentary canal of a rabbit with those in either a potato tuber or a seed at different times of the year. By what agents are these changes brought about? Describe any one experiment you have performed in this connexion. (L.G.S.)

17. Explain how digestion and absorption of food are carried on in the frog. State briefly how these processes take place in Hydra. (J.M.B.)

18. Make a drawing of the alimentary canal of the frog and indicate the functions of the various parts. (C.W.B.)

19. Describe the appearance of the liver, pancreas, and kidneys as seen in the dissection of a frog or a mammal, and show by diagrams the position of the organs in the body. Briefly describe the work done by two of these organs. (C.L.)

20. State the names of three important compounds of carbon, hydrogen, and oxygen occurring in named plants. What happens to the substances you mention when the plant is eaten by an animal? From what sources did the plant obtain these three elements? (Ox. & C.)

CHAPTER XV

DIGESTIVE PROCESSES AND THE DIGESTIVE ORGANS OF CERTAIN PLANTS

MOST PLANTS DIGEST THEIR FOOD INTRA-CELLULARLY. We know already that digestion and assimilation are more particularly animal functions, made necessary by the fact that animals ingest solid food containing 'foreign' proteins, carbohydrates, and oils. Non-green plants, like animals, require organic food, but they can only absorb this food *in solution*. Hence they often send out enzymes into the food which will make it soluble and diffusible, and so capable of absorption. We shall examine some plants of this kind later.

Green plants are largely relieved of the need to digest and assimilate their food since they make their own. Yet all plants store some food, if only enough to supply their needs during the hours of darkness, when photosynthesis has ceased; and many store large reserves of food for future use, often laying it up one season for use in the following one; such stores are found in all seeds, in carrots and other root vegetables, in bulbs, in the trunks of trees, &c. It is these stores which supply the materials necessary for rapid growth in early spring.

Such reserves are nearly always solid and indiffusible; when they are required enzymes are produced in the actual storage cells, and the food is digested within the cell in which it was deposited, each cell dealing with its own store. With the few inevitable exceptions, plants have no special digestive organs. It is to these few exceptions that our attention will now be turned. (Cp. also Chapter XXVII.)

INSECTIVOROUS PLANTS

These insectivorous plants are an interesting group which, as their name implies, capture and digest animal food (insects). They are green, and manufacture their food in the usual green-plant fashion; but they also capture insects in one way or another, using them as sources of additional nitrogenous food.

Some 500 kinds of insectivorous plants are known to botanists, but, of these, only three genera occur wild in England. Let us look at these interesting plants, the sundews, butterworts, and bladderworts.

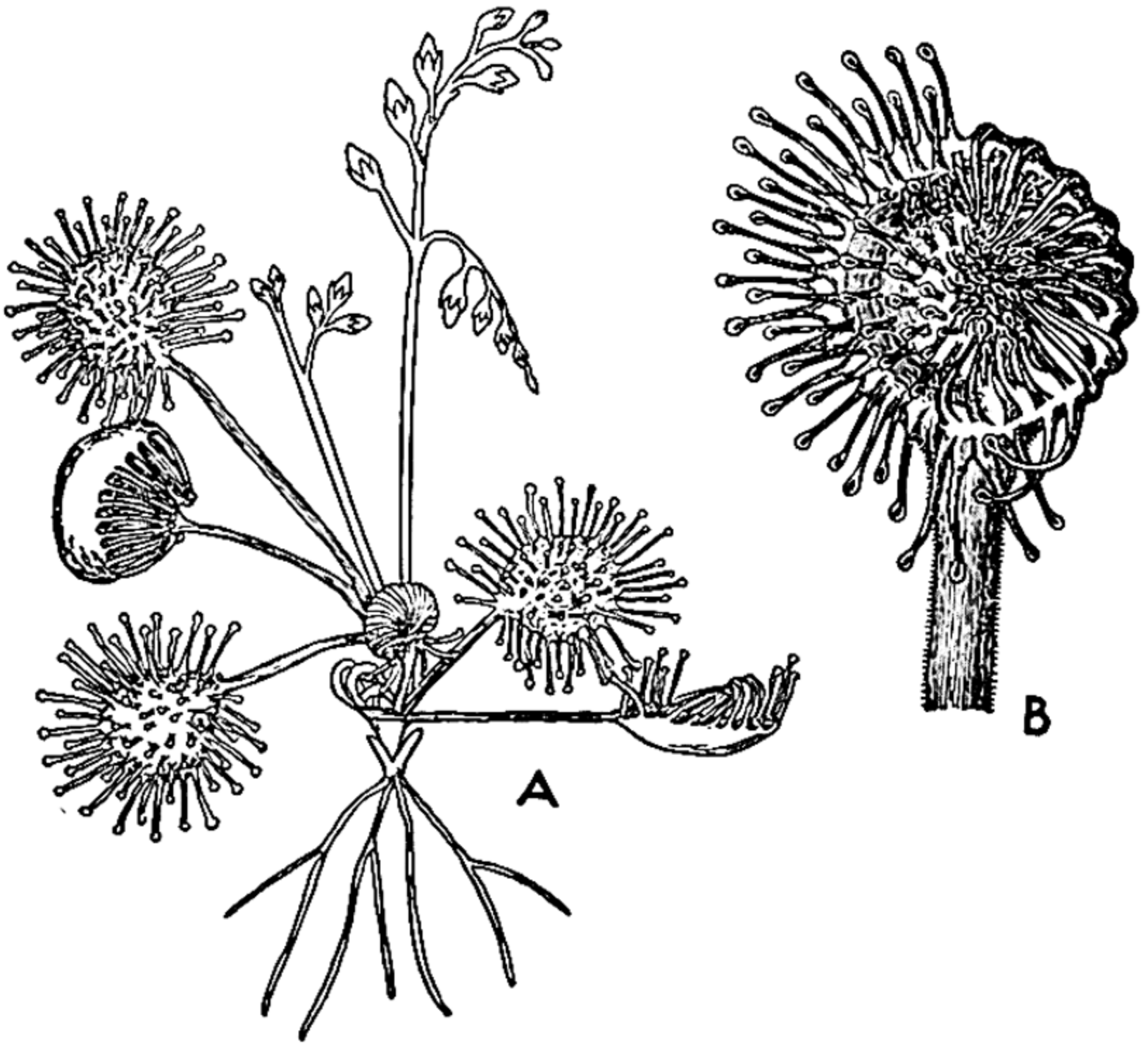


FIG. 44. **A.** Sundew plant (×2). **B.** Single leaf (×4)

THE SUNDEWS (DROSERA). These plants occur in nearly all parts of the world, wherever bogs occur. About forty different species are known, of which three are British.

Exercise. Examine and sketch a sundew plant; notice particularly the appearance of the leaves, and draw one of these leaves under a lens. Grow the plant in a basin with wet moss; it often grows best if covered with a bell jar.

Experiment 64. Select young leaves which have large drops of 'dew' on their tentacles, and place a minute fragment of raw meat on one of the long tentacles of each leaf. Watch the behaviour of the tentacles, carefully time them, and make enlarged sketches of the leaves so treated at intervals of ten minutes.

Experiment 65. Repeat experiment 64, placing the fragments of meat on the middle of the leaf.

All the sundews are low-growing rosette plants, which nestle among the bog-mosses of their characteristic haunt, the peat bog. Their leaves are covered with delicate red tentacles, each tentacle ending in a small round knob, like the head of a pin. They are true *glands*, secreting a shiny, sticky fluid, drops of which exude from the enlarged 'pin-heads'. These constitute the 'dew' which glitters in the sun and gives the plant its name. An insect, attracted by the 'dew', alights on the leaf, and, if it is small, its doom is sealed. The tentacles are sensitive to the lightest touch, and, stimulated by the contact, they begin to move. In about ten minutes those that were touched have moved through 90° and are holding the insect in position. Soon the stimulus is transmitted (cp. p. 256) to neighbouring tentacles. They also begin to move, and in the course of an hour every hair on the leaf has converged on to the unfortunate victim.

The contact also stimulates the glands in the tentacles and they secrete their sticky mucous fluid more rapidly. Smeared in this fluid, and becoming more involved the more it struggles to get free, the insect's fate is soon sealed. Its spiracles (cp. p. 292) become clogged with the 'dew'. It cannot get oxygen, and soon dies of suffocation. The tentacles still hold it firmly in position, and now their secretion alters in character. They begin to pour forth an acid juice, containing a protease belonging to the class of enzymes called pepsins (cp. p. 142). This attacks the carcass of the insect, and digests it as surely as our stomach digests the dinner-time beef; in this manner these sundews digest and absorb organic food.

THE BUTTERWORTS (PINGUICULAS) are another group of insectivorous plants, containing three species common in Britain.

Exercises

Examine and sketch a butterwort plant; examine the leaves carefully, and draw one as seen under a lens.

You are given a transverse section of a butterwort leaf, mounted on a slide. Examine with a microscope and notice the glands on the upper surface.

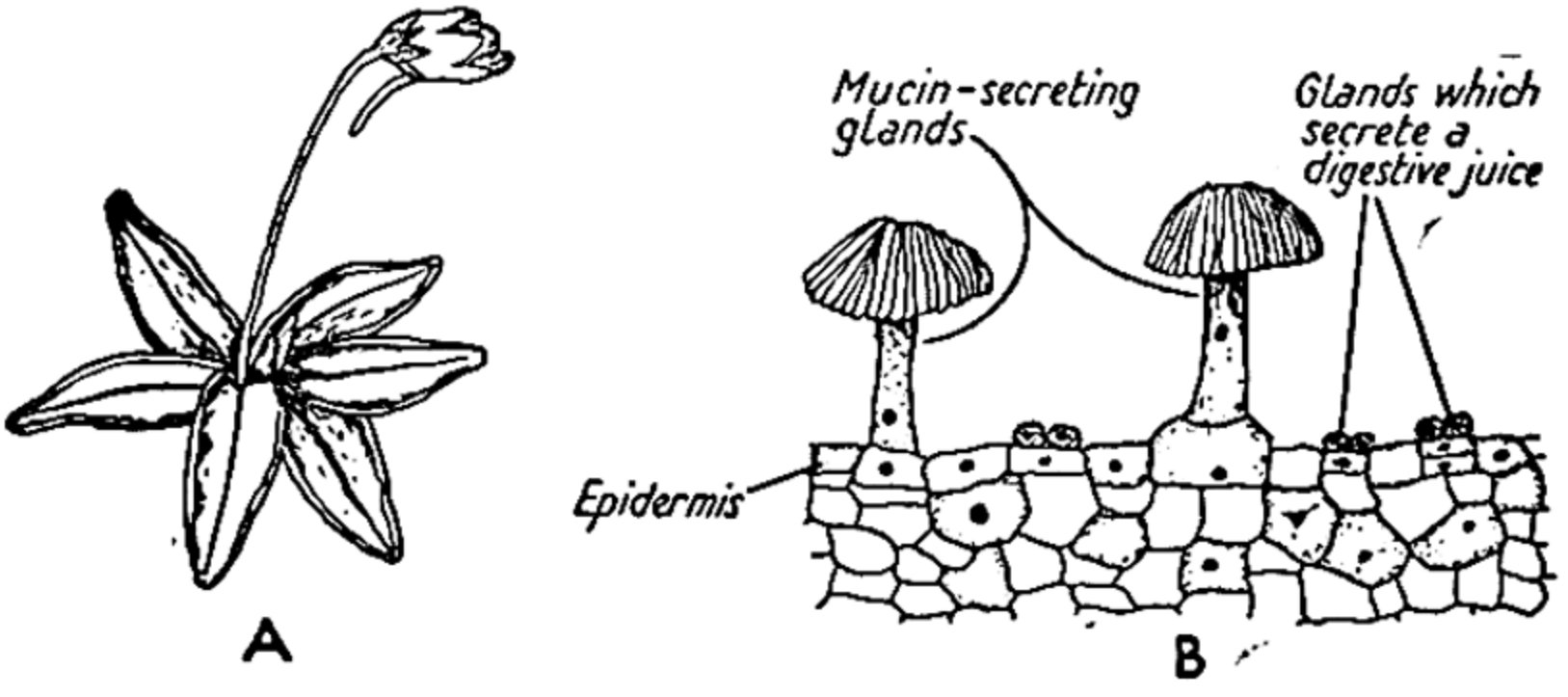


FIG. 45. **A.** Butterwort plant, viewed from above (×½). **B.** Part of leaf, in transverse section, showing glands (as seen under microscope)

The butterwort grows on the damp, dark soil of moors, on wet bogs, along the banks of brooks, and in other wet places.

Each of its oval leaves has upturned margins, which convert it into a flat-bottomed trough. On the surface of the leaf are two kinds of glands: small mushroom-shaped structures, large enough to be seen with the naked eye; and tiny digestive glands, which secrete a liquid containing a protein-digesting ferment. The larger glands produce mucin, a sticky fluid.

The mechanism resembles that of the sundew. The 'digestive glands' respond to a chemical stimulus only, pouring out their secretion when stimulated by some protein-containing substance, such as a tiny insect. The secretion contains *pepsin*, and the action of this fluid closely resembles that of the gastric juice in our own stomachs; by its aid any nutriment in the body of the unfortunate captive is digested and so prepared for absorption.

'Inasmuch as the gland cells of Butterwort absorb all the soluble parts of their prey, and reabsorb the solvent discharged by them, the

action of this plant's leaves is exceedingly like that of the animal stomach, and the process may fairly be regarded as digestion.' (*Natural History of Plants*, Kerner.)

THE BLADDERWORTS are a third group of British insectivorous plants, and of these, too, there are three British species.

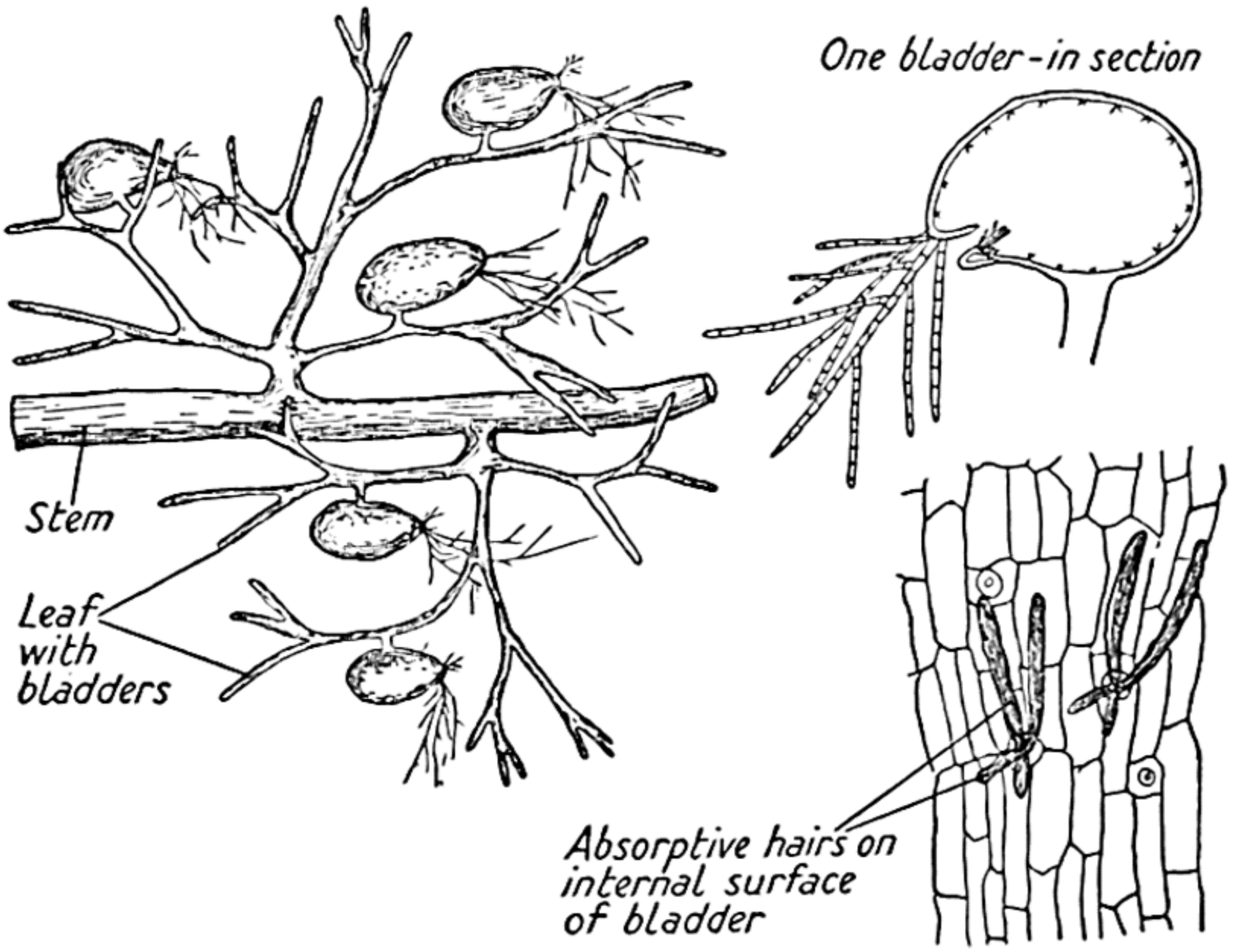


FIG. 46. Bladderwort, an insectivorous plant (all enlarged)

Exercise. Examine a short length of a bladderwort stem with a lens, and draw the leaves and bladders.

These bladderworts are rootless plants which grow submerged in the water of moorland pools. They have the finely divided thread-like leaves so often found on submerged water plants (cp. pp. 272, 277). At intervals we notice curious little bladders; these are nothing more or less than traps for tiny insects. Each bladder has a small lid which only opens inwards, and an insect caught in the bladder cannot escape, as the lid cannot be opened from the inside.

The trapped insects eventually die from suffocation or

starvation, and then decay. No enzymes are formed by these bladders; they are not digestive, but trapping and absorbing organs. The inner face of the bladder is beset with absorbing hairs, which suck up the products of decay. This decay is the result of bacterial action (cp. p. 122).

Thus all these insectivorous plants obtain animal food, which supplements their other sources of supply.

THE DIGESTIVE LAYER OF THE SCUTELLUM IN THE SEEDS OF CEREALS.

The maize grain. As a second interesting example of a group of plants with definite digestive organs, let us examine the single-seeded fruits of the cereals—maize, oats, barley, rye, &c. The seeds of these plants are enclosed in the fruit case (pericarp), and seed-coat and pericarp are closely adherent. The whole structure is called a grain.

The maize is the largest of the grains, and therefore most suitable for a first examination. The embryo is relatively small, and does not fill the grain; it rests upon a mass of reserve food, the *endosperm*, which occupies the bulk of the space within.

Exercises

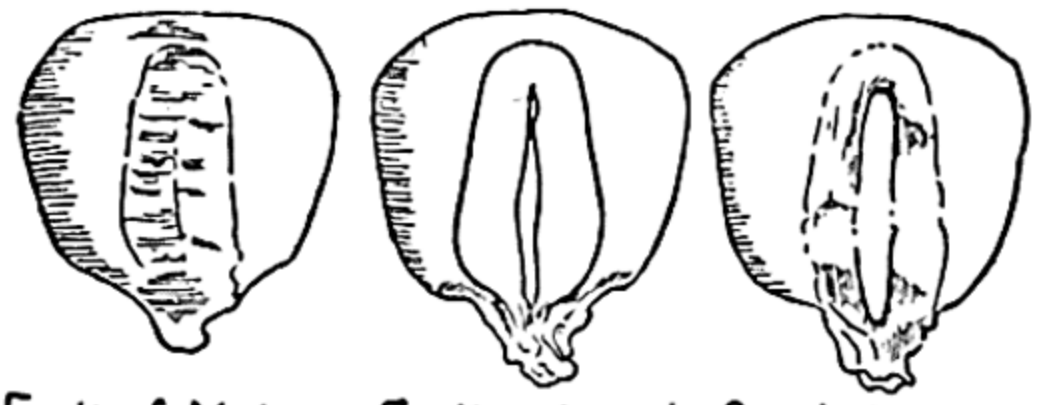
Examine soaked maize grains. Notice the yellowish skin, which is pericarp (fruit-coat) fused with testa (seed-coat). The grain corresponds to the bean pod rather than to the bean seed. Observe the roughened end, which marks where the fruit was attached to the axis of the cob. On one side recognize a light oval patch. This is the embryo plant, visible through the pericarp, &c. The rest of the grain is filled with endosperm.

Cut one grain transversely, across the middle of the embryo, and another longitudinally down its length. Also dissect out the embryo from grains which have been in water for some days. Draw these sections, and try to discover the structure of the embryo.

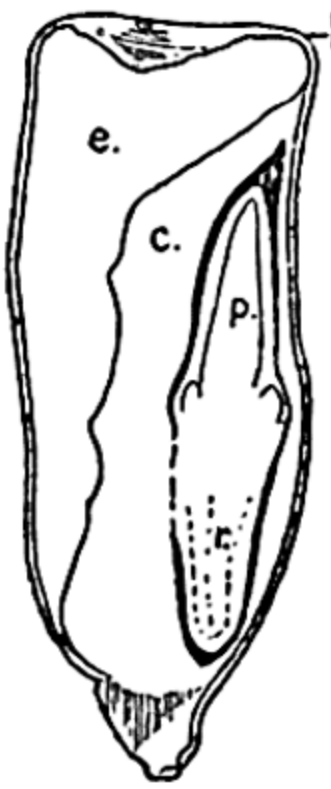
Test the endosperm for starch (iodine test) and protein (Millon's test). It contains both.

The embryo plant of the maize grain. If the maize grain is cut longitudinally, the axis of the embryo plant is visible. The radicle is at one end, encased in a small root-sheath; laterally

there is the plumule, in which several leaves are visible, wrapped round each other (cp. Fig. 47). Attached to the upper portion of the root, and forming the other end of the axis of the embryo, is a large shield-shaped outgrowth, the scutellum or cotyledon. This is both longer and wider than



Fruit of Maize. Fruit skinned. Cotyledon partly removed, to show plumule and radicle.



Fused pericarp and testa.
e. endosperm. c. coryledon - of which the part next to the endosperm, is called the scutellum, and absorbs the food stored in the endosperm. p. the plumule.
r. the radicle.

FIG. 47. Longitudinal section of maize grain (×2)

the plumule, which it partially enfolds. Its outer edge is in close contact with the endosperm. Thus the embryo consists of radicle, plumule, and scutellum (cotyledon). We see that the maize embryo has one cotyledon only; this is characteristic of all *monocotyledonous* seeds. It has a quantity of reserve food which is stored outside the embryo plant; this is a characteristic of all *endospermic* seeds.[1] The surface layer of the scutellum, where it touches the endosperm, consists of elongated cells, about three times longer than they are broad, with finely

[1] The bean seed previously described had no such store (cp. p. 85). It is non-endospermic.

granular protoplasm and conspicuous nuclei. This is the epidermal or *digestive layer* of the scutellum. Its function is to digest and absorb the reserve food when germination begins.

A few hours after the grain has been soaked and given conditions favourable to growth, marked changes begin to occur in the cells of this epidermis. The protoplasm becomes cloudy and much more coarsely granular; the cells themselves begin to enlarge until, at the end of the third day of germination, they are three or four times their original size. Soon after these changes have started in the digestive layer, the walls of the adjacent endosperm cells begin to dissolve and the contained starch grains become pitted. The reserve food is in process of digestion.

The cells of this epidermis produce enzymes (the carbohydrases diastase and cytase, and probably proteases as well), which escape into the endosperm. The functions of the scutellum are (1) to digest the endosperm, (2) to absorb the soluble foods, and (3) to transmit them to the growing axis. It is as much a digestive organ as is the gut cavity of a vertebrate animal, for, like the intestine of such animals, it both digests and absorbs food.

These examples show that though extra-cellular digestion, which is the typical form of digestion in animals, is not usual in plants, yet it does occur in certain cases. There is no hard-and-fast dividing line separating the living processes in plants and animals; the great functions of respiration, digestion of food, &c., are similar in both.

QUESTIONS ON CHAPTER XV

1. Where is the food stored in a bean seed produced, and how does it reach the storage cells? Describe the changes which it must undergo before it can be used by the developing embryo, and give one experiment which supports your statements.

2. Explain fully from what sources (*a*) the ordinary green plant, (*b*) the insectivorous plant, obtains the nitrogen it requires.

3. Describe in detail the methods by which (*a*) sundew and (*b*) butterwort obtain organic food.

4. Write a short essay on insectivorous plants.

5. By means of labelled diagrams describe the structure of the maize (or wheat) grain. Explain concisely how the reserve food-substances are made available for the nourishment of the young plant.

6. Compare the nourishment of the young maize plant with that of any young mammal fed entirely on its mother's milk.

7. By means of labelled diagrams only, show (*a*) the external appearance and internal structure, and (*b*) *three* progressive stages in the germination of a grain of maize or wheat. Explain the work done by the cotyledon during the germination of the grain selected. (J.M.B.)

8. What do you know of the ways in which plants and animals store food material? Indicate how reserve food material is made available when it is required, and give two examples, one from plants and one from animals. (Ox.L.)

9. What do you understand by 'storage of food' in plants? Name three substances so stored, and state in what organs they occur. What is the nature of these substances and what becomes of them? (C.L.)

CHAPTER XVI

OTHER WAYS OF OBTAINING FOOD

PARASITES, SAPROPHYTES, SYMBIOSIS, ETC.

METHODS OF FEEDING. So far we have examined two ways of feeding. The ordinary green plant makes its own food, i.e. is *holophytic*; the typical animal lives on organic matter obtained from plants and other animals, i.e. it is *holozoic*. Two other methods of feeding remain to be discussed. Many creatures are *parasites*, living on or in the bodies of other organisms ironically called their 'hosts', from whom they steal their food. Then again there are certain colourless plants known as *saprophytes* (Gk. *sapros* = rotten) that live on decaying organic matter which they can only absorb in solution. Let us study these parasites and saprophytes more fully.

PARASITES

There are a very large number of parasites; we are reminded of the familiar adage about 'big fleas having little fleas', &c.; probably no living organism is quite immune from attack. They range in structure from simple bacteria to parasitic flowering plants and even vertebrate animals. Many of these creatures are degenerate in structure and have quite lost the ability to provide for themselves; we find plants with mere vestiges of roots and leaves, animals reduced to little more than food-imbibing and reproductive machines. Their ways of living are extraordinarily diverse; the parasitism may be: (*a*) of one animal on another, (*b*) of one plant on another, (*c*) of an animal on a plant, (*d*) of a plant on an animal; cases even occur where the male animal is parasitic on the female. Often the parasite has two or three different 'hosts' at different stages in its life-history. The tape-worm that comes to maturity in the human intestine begins life in the pig. The unicellular parasite which causes malaria in man completes one portion of its life-cycle in the mosquito (cp. p. 312). The

very destructive rust disease of wheat is caused by a fungus (Puccinia graminis) which uses the barberry as a second host.

PLANT PARASITES.

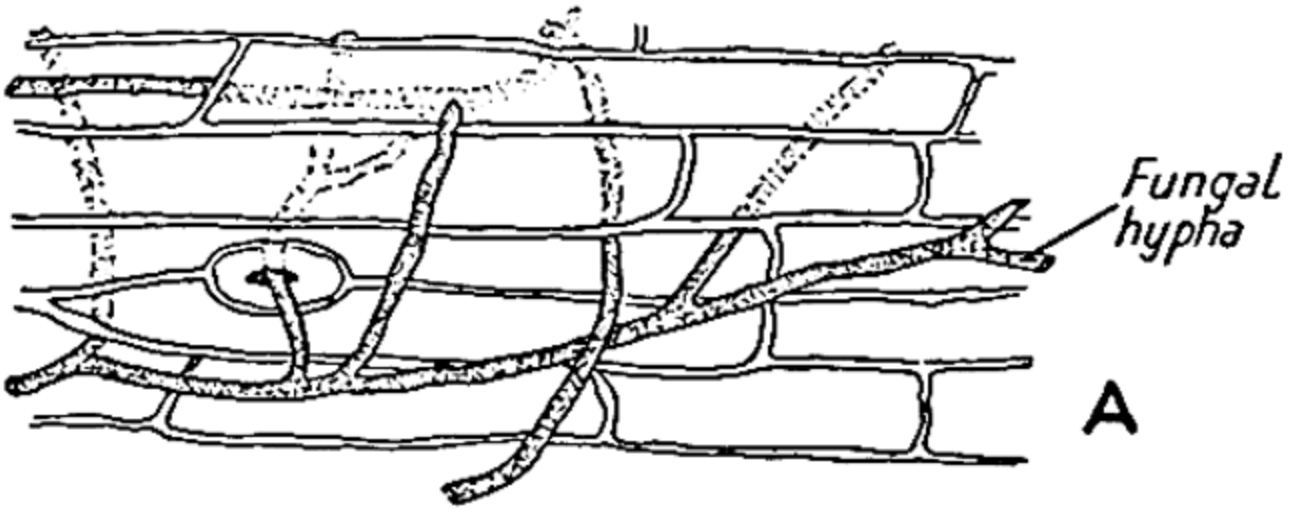
Parasitic bacteria are very numerous; the group includes the organisms which cause boils, blood poisoning, pneumonia, leprosy, tuberculosis (consumption), diphtheria, typhoid fever, &c., in man. Some of these are transmitted in the air, others reach us in our food, our milk or water, others by direct contact with an infected person (contagion). They cause tremendous loss; about one-seventh of all human deaths are due to tuberculosis, and it is estimated that at least 50 per cent. of all deaths are caused by bacterial infection. Not man alone, but practically every living organism, is susceptible to the attack of parasitic germs.

Parasitic fungi. Many fungi are parasites; they cause the plant diseases known as smut, scab, rust, mildew, &c., which result in great loss to agriculture. Among animal diseases due to a fungus we may mention one that causes a regular epidemic among house-flies in autumn. Perhaps you have noticed these dead flies, adhering to windows, &c., surrounded and held down by a white halo formed of the hyphae of the fungus (Empusa muscae) that killed them. Or perhaps you find the goldfish in your aquarium liable to the attack of a fungus. Ringworm is a familiar fungal disease which attacks the human skin.

Mildews are parasitic fungi which live in or on the leaves and fruits of flowering plants. They take their name from the white cobweb-like mass of fungal hyphae, particularly characteristic of the *powdery* mildews, which invest the surface of the infected leaf; these hyphae send suckers into the epidermal cells by which they absorb nutriment.[1] The mildews cause much damage to certain cultivated plants; roses, especially ramblers, are very liable to attack; the grape-vine mildew (which is of American origin and was not known in Europe until 1845), the hop and gooseberry mildews do very considerable damage

[1] The *downy* mildews (e.g. potato blight) penetrate farther into the tissues of the host. (Cp. Fig. 48 A.)

to the crops they attack. They can all reproduce by tiny spores (cp. Fig. 48 B) which are disseminated by the wind. These spread the mildew so rapidly that whole areas may be devastated within a few days.



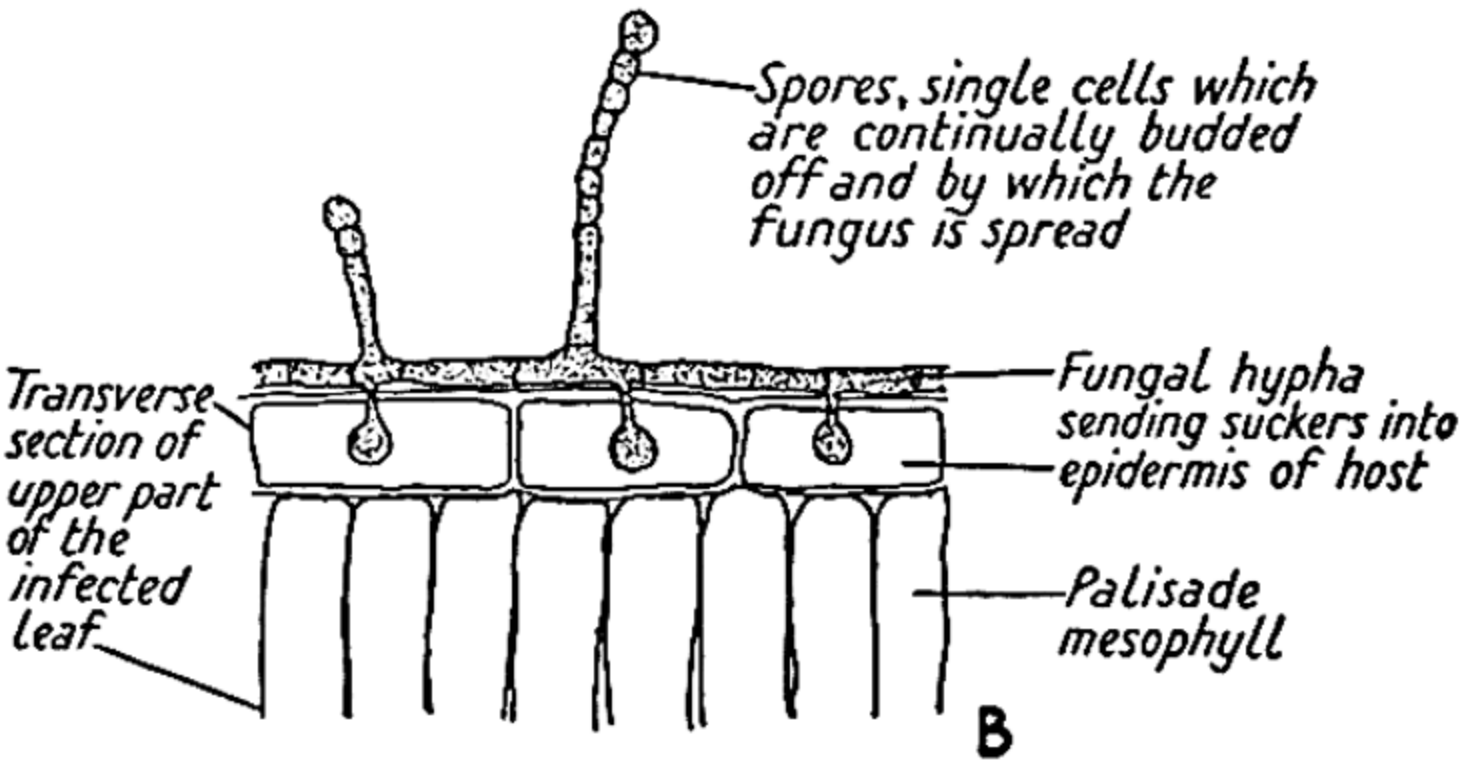


FIG. 48. A. Epidermis of a cress seedling. On it and penetrating it are the hyphae of a (downy) mildew fungus. B. Another (powdery) mildew fungus, on the leaf which is its 'host'

It was the spread of the 'late blight' caused by the potato mildew which caused the great Irish famine of 1845.

Parasitic flowering plants. Certain flowering plants are completely parasitic, forming no chlorophyll and being dependent on the host plant for all their food. Others are only partial parasites; being green they can make their own carbohydrates, but they absorb a part of their nutriment from some other organism.

Dodder is a well-known member of the former group. It is a climbing plant, and we often find its delicate thread-like stems wound round plants of gorse, heather, clover, thyme, &c. (cp. Fig. 49 A). The parasite sends suckers into the host at the points of contact, which penetrate the tissues of the host plant and absorb food. A dodder cannot make any food for itself. It has no root and only tiny vestigial colourless leaves. Dodder flowers are quite perfect, however, resembling those of the convolvulus, and the plant makes numerous seeds. The *seedling* possesses a minute thread-like radicle, but this very soon shrivels and decays (cp. Fig. 49 A). Very early in its life the dodder becomes completely parasitic; it has quite lost the power to make its own food, and the whole seedling dies if it does not come in contact with a suitable host. The plumule, which rotates as it grows, establishes such contact, and suckers are formed. These become connected with both wood vessels and sieve tubes of the host, so that the parasite can now absorb both water and food (cp. Fig. 49 A).

Broomrapes and toothworts are other complete parasites often found in British woods. Both are root parasites, sending their suckers into the roots of the host plant. Broomrapes often grow on broom and ivy plants, toothworts on hazel, beech, &c.

Dodder is a colourless plant with vestigial leaves; mistletoe is green with well-developed leathery evergreen leaves. It can make carbohydrate food and is therefore only partially parasitic. It sends absorptive suckers into the conducting tissues of its host plant, often an apple, poplar, or oak tree.

The fruit of mistletoe is the familiar berry, and its seeds are dispersed by birds, chiefly by thrushes. If one lodges in a crevice on a suitable tree, it germinates slowly and sends out a radicle which curves towards the bark. Soon, from this radicle, a sucker is produced which penetrates the bark and makes its way through cortex and bast into the wood of the host. It can now absorb water and salts, and slowly the development of the seedling proceeds. In the second year it forms its first pair of leaves, and gradually a comparatively large plant may be produced.

Among common semi-parasites are yellow-rattle, cow-wheat, eye-

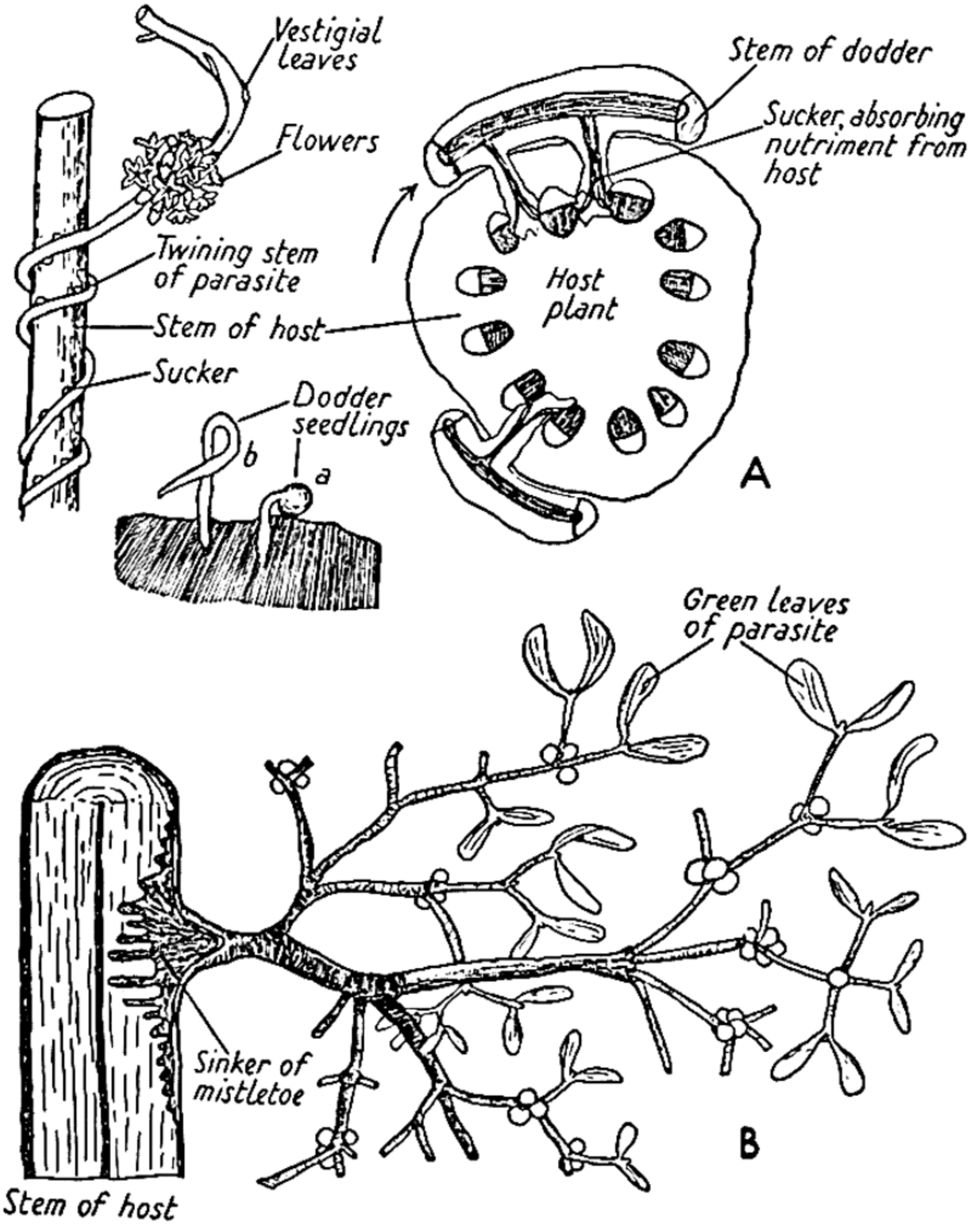


FIG. 49. PARASITIC PLANTS. **A.** Dodder, a complete parasite with vestigial leaves. **B.** Mistletoe, a partial parasite with green leaves

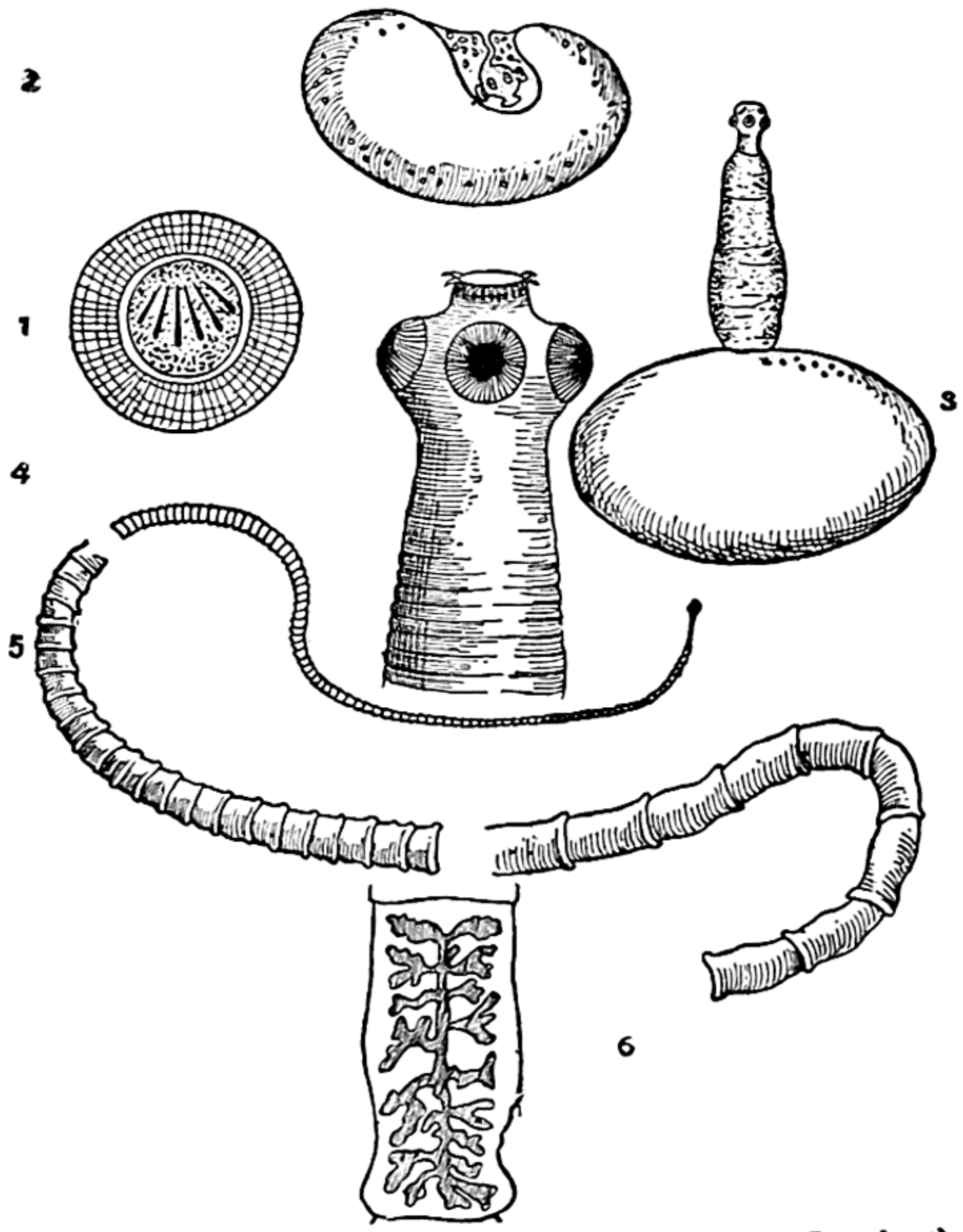


FIG. 50. THE LIFE-HISTORY OF A TAPEWORM. (After Leuckart)

1. Six-hooked embryo in egg-case. 2. Bladder-worm stage with head turned in. 3. Bladder-worm with head thrust out. 4. Enlarged head of mature worm, showing suckers and hooks. 5. General view of worm. 6. One ripe segment, showing the branched uterus which is full of eggs in their protective shells

bright, and other small plants with green leaves which have nothing above ground to betray their parasitism. They are all root parasites, sending suckers into the roots of grasses and other meadow plants which serve them as hosts.

Exercise. Examine and draw any parasitic plants that are available. Examine also under the microscope prepared sections which show the connexion between the various parasitic plants and their hosts.

ANIMAL PARASITES.

Animal parasites are very numerous, including examples from every main group of the animal kingdom, from unicellular forms on the one hand to vertebrates on the other. Man himself is preyed on by a large number; for example, all the blood-sucking external parasites (fleas, lice, leeches, mosquitoes, &c.) and many internal ones, such as the parasitic amoeba which causes dysentery, and the many parasitic worms (flukes, tapeworms, hookworms, round worms, &c.); these are all very prevalent, especially in the tropics. In 1909 it was found by the Rockefeller sanitary commission that

'more than two million people in the Southern States [of U.S.A.] are infested with hookworm'. They estimated that 'in the inhabited territory between 30° N. and S. of the equator, more than a thousand million people harbour the parasite, the infection among some races amounting to nearly 90 per cent. of the entire population. . . .

'This disease has probably been an important factor in retarding the economic, social, intellectual and moral progress of mankind.'

The same thing is true of many other human parasites (cp. pp. 203, 204).

The structure and life-history of the common tapeworm (*Taenia solium*). Tapeworms are internal parasites which, in the adult condition, usually infest the intestine of a vertebrate host. The early ('bladder-worm') stage is found in a second host, often another vertebrate. The life of these parasites falls into three stages:

(i) A very short 'free' stage, i.e. one outside the body of either host.

(ii) Its life in the first host, during which it develops from

a small hooked embryo (cp. Fig. 50 (1)) into a bladder-worm or cysticercus (cp. Fig. 50 (2)).

(iii) Its development from bladder-worm to maturity in the second host.

The hosts of some common tapeworms are given below:

	Free stage (Hooked embryo)	*Immature stage in first host (Bladder-worm or cysticercus)*	*Adult stage in second host (Tapeworm)*
Species A		In muscle of pig	In intestine of man
„ B		In muscle of ox and other hoofed animals	In intestine of man
„ C		In rabbits, hares, &c.	In dog and wolf
„ D		In mouse	In cat
„ E		In brain of sheep and other hoofed animals, causing 'staggers'	In dog
„ F		In man, usually in the liver, where it can cause great damage to the tissues	In dog and wolf
„ G		In pike, trout, and other fish	In man

Let us study the life-history of the first member of this series, Taenia solium, which infests (*a*) the pig and (*b*) man. The mature worm, which lives in the human intestine, may be from 6 to 9 feet long. It consists of a 'head' and of a varying number of segments (proglottides)—there may be as many as 850. As 'ripe' proglottides fall off behind, new ones are continually formed in the region just behind the head, the so-called 'neck'.

This head has four muscular suckers and a crown of hooks (cp. Fig. 50 (4)) by which it attaches itself firmly to the wall of the 'host's' intestine. Behind it, in the neck region, slight transverse constrictions are visible which mark the beginnings of the newly formed segments (proglottides). As we pass backwards these become larger and larger, until at the hinder end of the body we reach the region of mature proglottides.

Each such proglottis contains a complete set of reproductive organs, both male and female (cp. pp. 428, 496), the animal being hermaphrodite. For a parasite this condition has obvious advantages. If, as in most animals, a male and female were required for the continuation of the race, the chances of such continuance would be infinitely remote. The host would obviously have to harbour two parasites of different sex before reproduction could occur. In this creature, apparently, each proglottis can fertilize its own eggs.

The proglottis, when it becomes mature, contains a large number of eggs in its distended 'uterus' (Fig. 50 (6)), each egg being enclosed in a firm, resistant shell. The ripe proglottis now becomes detached from the rest of the worm and passes out from the body of the host in the faeces. Development of the new animal has already begun, and the egg-shell contains at this stage a tiny embryo which consists of a solid mass of undifferentiated embryonic cells; on the surface of the mass are three pairs of pointed hooks or spines (cp. Fig. 50 (1)).

This embryo cannot develop any further until stimulated to renewed growth by entry into a fresh host, in this case, a pig. The expelled proglottis either decays and sets free the eggs, or is swallowed entire. In either case, if the egg reaches the alimentary canal of the pig, its shell is softened by the digestive juices and the little six-hooked embryo is set free. With the help of these hooks it bores its way through the wall of the intestine and into a branch of the portal vein (cp. p. 298). It is carried in the blood-stream until it reaches a small capillary (in the case of T. solium a capillary supplying the muscle cells). Here the embryo makes its way between the cells, which react to the irritation caused by the parasite by producing a cyst round it. The 'hexacanth' embryo now loses its hooks and develops into a bladder-worm (cp. Fig. 50 (2)). At no stage in its life has this animal a mouth or an alimentary canal. If its ancestors ever possessed such organs, they were gradually lost as the creature became more completely adapted to a parasitic mode of life; in this respect it is extremely degenerate (cp. p. 192). It is nourished, in both the bladder-worm and tape-worm stages, by pre-digested liquid food which it absorbs

from the tissues (or the food-canal) of its host through its whole surface.

The cysticercus (bladder-worm) consists essentially of a tapeworm 'head' with hooks and suckers, attached by a short neck to a relatively large bladder. The head is tucked in as shown in Fig. 50 (2).

No further development takes place in the pig, but when man unwittingly eats 'measly' and undercooked pork the creature begins to grow again. Stimulated by the new surroundings it thrusts out its head (cp. Fig. 50 (3)), its bladder being digested and absorbed. It fixes itself by the head to the intestinal wall. Abundant nourishment is provided by the semi-digested food around it and, from this head, a chain of proglottides begins to be formed. These become mature, pass out of the host, and each egg may start a new infection.

Exercise. Examine with lens and microscope mounted specimens of (*a*) whole worms; (*b*) the head; (*c*) bladder-worms. These latter are often seen when we open a rabbit for dissection. These creatures nearly always harbour the cysticercus stage of T. serrata.

SAPROPHYTES.

Saprophytic plants live on decaying organic matter. The group includes forms belonging to every subdivision of the plant kingdom, from the lowest (bacteria and simple fungi) to the highest (flowering plants). The saprophytic bacteria are the world's most efficient scavengers, for they clear away organic refuse (cp. p. 122). They do this by living among it, decomposing it, and using the products of this decay as food.

'These minute bacteria', says Sir R. Lankester, 'cannot get their food into them as they have no stomach. Conversely, they get into their food, acting upon it by ferments (enzymes) diffused from their living surfaces.'

The proteins in such refuse are broken down, step by step, each stage the work of a different group of bacteria, until finally some of the nitrogen is in the form of nitrates (p. 122), while the carbon has been given off as carbon dioxide. Nitrates, as we have learned (p. 74), are, with carbon dioxide, &c., the

raw materials needed by green plants to build up proteins once more. So the circle is complete; there is no waste in nature.

DECOMPOSITION OF NITRATES. This decomposition of nitrogenous compounds does not always stop, however, when they have been converted into nitrates. Denitrifying bacteria may

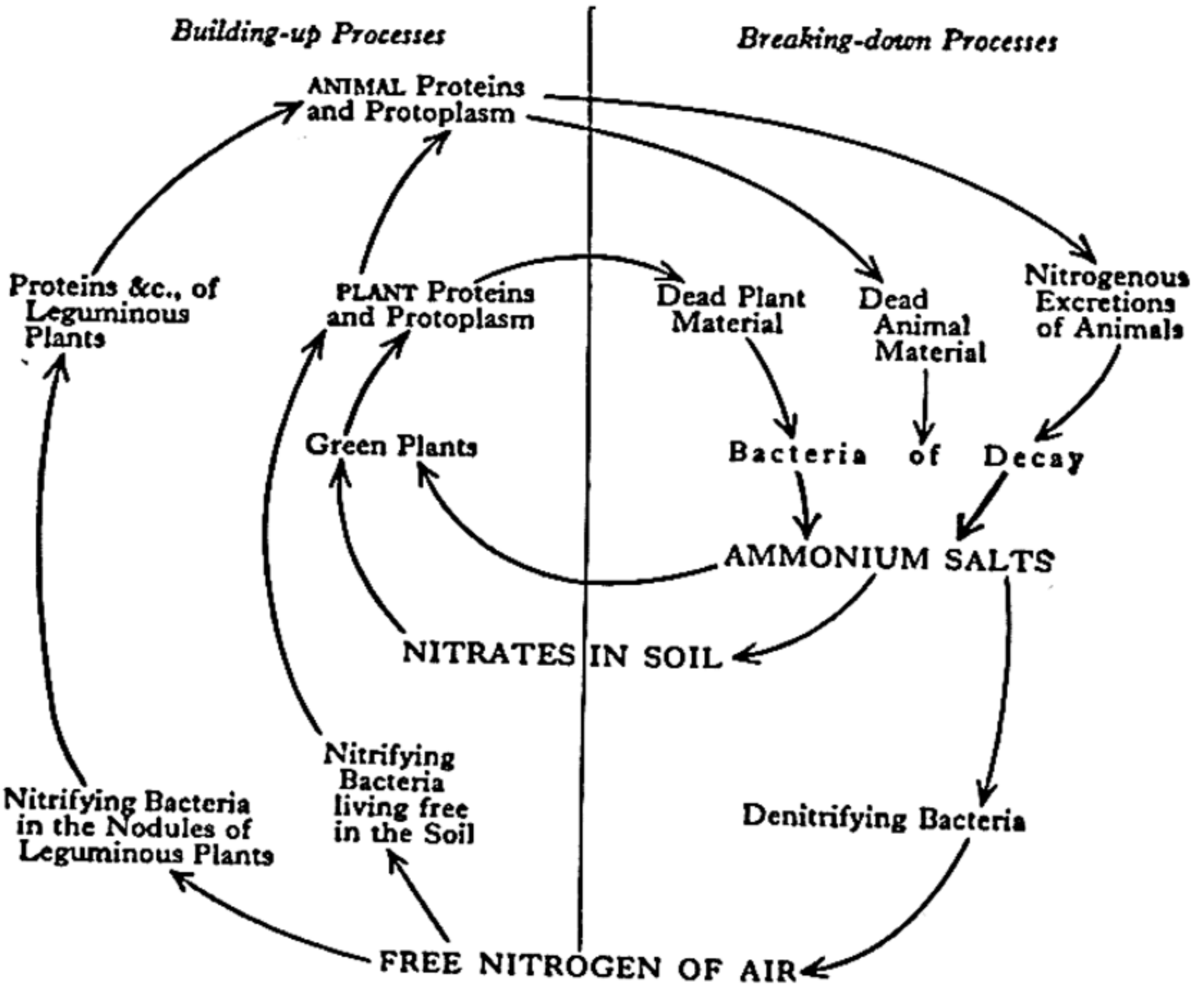


FIG. 51. The Nitrogen Cycle

carry the process a stage farther until, ultimately, gaseous nitrogen is set free. Such free nitrogen is useless to most living organisms (cp. p. 70), but there are certain nitrogen-fixing bacteria which prevent its irrevocable loss; they 'fix it', as we have learned already (cp. p. 123), that is, they cause it to unite with other elements to form nitrogenous compounds once more. These compounds are ultimately used by the green plant.

CIRCULATION OF NITROGEN. From all these facts we learn that the nitrogen of the world is in continuous circulation. This circulation is summarized in Fig. 51.

SAPROPHYTIC FUNGI.

Mucor. If we expose some bread to the air for a few days, keeping it moist, it becomes covered with various saprophytic fungi, the spores of which are present in the air. One of the commonest of these is Mucor or the bread mould, which, when it appears, soon covers the bread with a dense network of fine white hairs. The whole plant consists merely of a mass of branching threads or hyphae which form the mycelium or body of the plant (cp. Fig. 52 A).

From this mycelium certain upright hyphae arise which grow out away from the bread and into the air. These produce the reproductive bodies or *sporangia.* They are spherical structures, at first cream in colour, but becoming black as they ripen (cp. Fig. 52 B).

Exercises

Examine a culture of Mucor on bread. Notice the condition of the bread, the general odour of decay, and the various discolorations, green, orange, &c., which indicate the growth of saprophytes—bacteria and fungi.

Mount some of the Mucor hyphae in water and examine under the microscope; notice the protoplasm lining the thread, which is not divided transversely into separate cells. Nuclei are present in it but are too small to be seen without special staining.

Cut off some of the sporangia, mount them in water, and examine with a lens or microscope. Each is a small sac, cut off from the hypha by a cross-wall, and containing a large number of minute spores. Each spore is a reproductive cell; when these are ripe the wall of the sporangium bursts and the spores are shot out into the air. The rupture of the sporangium may often be observed under the microscope; it is from such air-borne spores that new plants develop.

How Mucor obtains its food. Mucor is a saprophyte, i.e. it requires soluble organic food. Its hyphae penetrate between the particles of bread (or other food material) and produce enzymes which pass out into this substratum. These enzymes act on the food there, making it soluble and diffusible. In this condition it can be absorbed by the Mucor hyphae; the whole mycelium is specialized to digest and absorb organic food.

Mucor a 'fermenting' agent. In the Far East the fact that Mucor can bring about digestion has long been put to practical use. Chinese 'yeast', for example, is really a mixture of yeast cells, Mucor spores, and bacteria. When added to cooked rice the mush soon becomes covered with a rich growth of Mucor, which 'sugars the rice' by the enzymes it gives off. The way

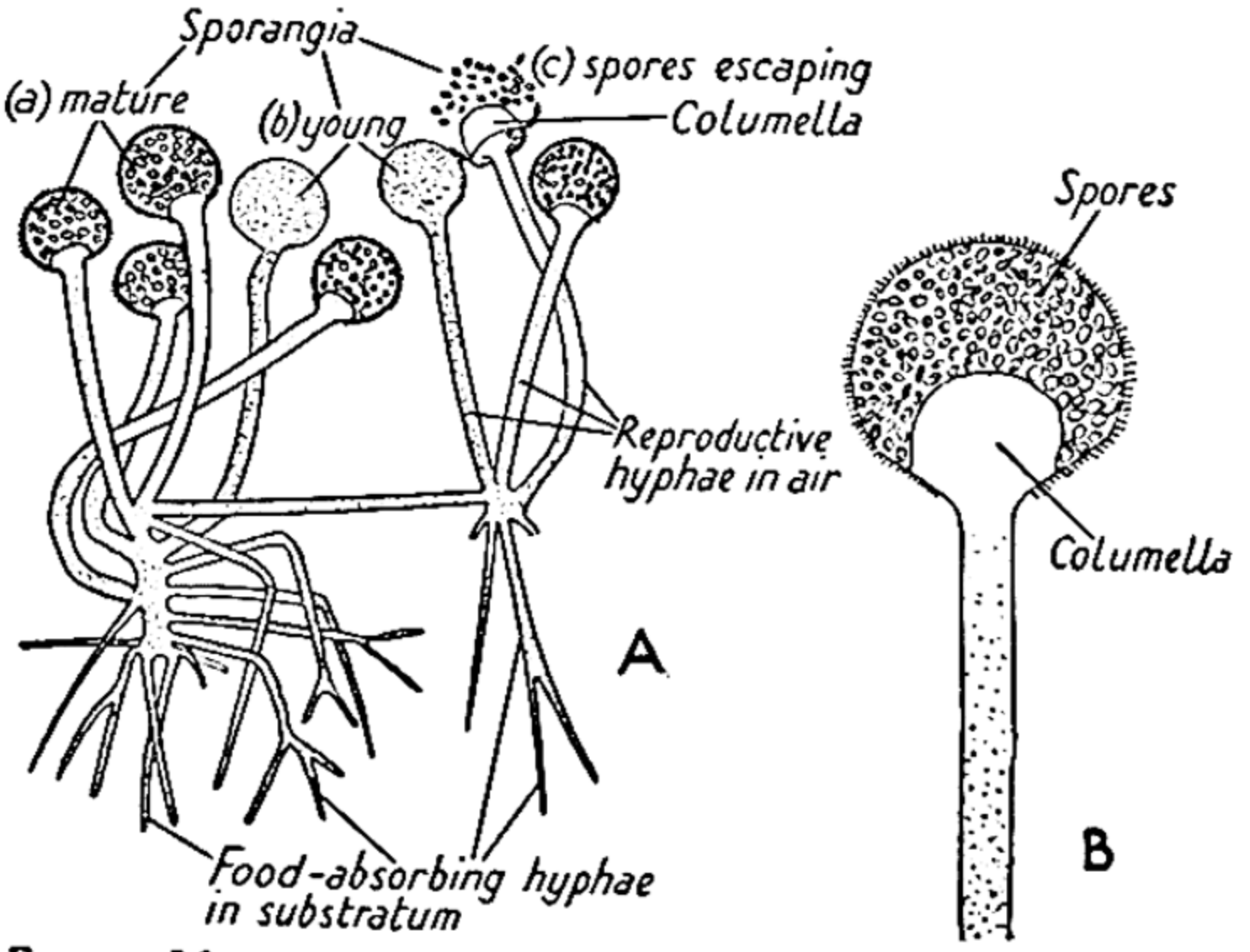


FIG. 52. MUCOR. **A.** Portion of plant. **B.** One sporangium (more highly magnified)

is thus prepared for the yeasts, which convert the sugar to alcohol (cp. p. 262). The Saké or punch of the Japanese is produced in the same way.

Another well-known group of saprophytic fungi includes the *mushrooms, toadstools, and puff-balls.* The mushroom plant, like Mucor, consists of a mycelium of colourless branching hyphae; unlike Mucor, the hyphae have cross-walls, and tend to become closely interwoven. This mycelium lives underground among the decaying horse and cow manure, &c., from which it obtains its food. The edible portion of a mushroom, the part by which alone it is known to most of us, is the reproductive body or 'fruit'. When ripe there are on its under surface

numerous 'gills' or 'lamellae', which bear minute brown spores. They are free on the surface of the gills, not enclosed in sporangia, as in Mucor. It is estimated that one medium-sized mushroom may produce as many as 1,800,000,000 of these spores. Each spore can give rise to a new plant.

Exercise. Examine and draw mushrooms at various stages of development, sketching them both externally and in longitudinal section. Follow their development from the small solid 'button' to the final stage.

Flowering plants also include a few saprophytic forms, which should be examined if possible. The bird's-nest orchid is a fairly common object in British beechwoods. Its complete lack of green colour tells us that the plant is not holophytic, and if we dig it up we find that it has a very characteristic and unusual root system. This is the 'nest' to which the plant owes its name. The yellow bird's-nest is another saprophyte of somewhat similar habit, though belonging to a very different group.

Exercise. Examine and sketch plants of the bird's-nest orchid and the yellow bird's-nest, particularly noticing the root system in each.

Partial and complete saprophytes. Mucors and mushrooms are completely saprophytic, and so are the flowering plants just described. They contain scarcely a trace of chlorophyll, and depend on organic matter for all their food.

Among flowering plants we find many partial saprophytes; they are green and able to carry on photosynthesis, but they also use organic food; many forest trees, most orchids, and many woodland plants live in this manner. These plants are not able to prepare their own organic food for absorption by excreting digestive enzymes on to it, as do the saprophytic fungi (cp. p. 200); they depend on the services of a fungal 'servant' who does this work for them. The fungal hyphae envelop the roots of the saprophytic flowering plant, the fungus getting shelter, protection from drought, and various other benefits from the association.

Mycorrhiza. This close association of a root with fungal hyphae forms a structure known as a mycorrhiza. In many cases the fungus merely envelops the outside of the root; this condition is found in most forest trees, in many orchids, &c. In other forms, for example in the bird's-nest orchid, in heather, heaths, and other moorland plants, the fungal hyphae actually penetrate the epidermis of the root and form a fungus-infected zone in the outer cortex.

Symbiosis. A partnership between two living organisms for their mutual benefit, like that occurring in a mycorrhiza, is called symbiosis. We have seen that the fungus obtains shelter, &c., while the flowering plant obtains organic food in a state ready for absorption. There are many cases of symbiosis, both in the plant and animal world. That intimate partnership between an alga and a fungus which forms a *lichen* is one of the best known. This 'mutual-aid society' enables these plants to flourish where no other living thing can survive, on high mountain peaks and near the earth's poles (e.g. reindeer moss).

Commensalism. We may mention here another rather looser form of partnership called commensalism. There is, for example, a rhinoceros bird which lives on 'ticks', parasitic animals which it picks from the rhino's back; at the same time it warns its dull-witted friend of the approach of danger. Then again, certain sea anemones are often found on empty whelk shells in which crabs are living. They benefit by the fragments of food which are let fall by the crab, while the crab is protected from its enemies by the stinging hairs of the anemone.

These anomalous ways of feeding—parasitism, saprophytism, symbiosis, commensalism—present many features of interest and will repay more detailed study.

BIOLOGY AND DISEASE. One of the greatest services rendered by the biologist to mankind has been to show him the true nature of parasitic diseases. Understanding their nature, he has often been able to get them under control or even to effect a cure.

Many of these diseases have terrible consequences. Whole races can be destroyed by them; it is believed that malaria

contributed to the downfall of Greece. In 1915 an American scientist affirmed that:

'The hook-worm disease stands with malaria as worse than war and the devastation of battles. Through the influence of these diseases, men and women of the South, bred from the best American colonial stock, sank lower and lower in physical degeneration and squalor; were derided and denounced as lazy and shiftless and condemned as worthless and a disgrace.'

To combat such diseases successfully the life-history of the parasitic organism must be known. The story of this modern fight against infectious and contagious disease begins with the great French scientist Pasteur.

Louis Pasteur (1822–95) was the first to show clearly the connexion between bacteria and disease. By discovering the bacterial cause of a very infectious and fatal disease of silkworms, which at that time (1865–70) was threatening the whole silkworm industry, he was able to show how it might be checked. It is estimated that, by this discovery alone, he saved his fellow countrymen enough to pay the whole indemnity imposed after the Franco-German war (1870).

Later he established the connexion between bacteria and a human disease, by showing that rabies is a germ disease, caused by infection through the bite of a mad (i.e. rabies-infected) dog. He also worked out the method of cure.

The story of his first human inoculation of a little boy who had been badly bitten, and of his watch by the child's bedside, is a very dramatic one, which you should read. Out of the first 350 cases treated by him only one died. Soon people were flocking from all parts to his institute in Paris.

Among his early patients were nineteen Russians who, early in 1886, had been bitten by a rabid wolf in the far province of Smolensk. In spite of the long journey and the time which necessarily elapsed before the cure could be started, the lives of sixteen of them were saved.

The whole science of bacteriology, all modern treatments of infectious disease such as vaccination, inoculation, antitoxin treatments, &c., all our sanitary precautions, all our systems of quarantine after exposure to infection, all these are among the direct results of Pasteur's

work. Further, it was his discoveries which inspired LORD LISTER, whose work on antiseptics inaugurated the period of modern surgery (cp. p. 520).

Among insect-borne diseases which have been successfully attacked are malaria, typhoid, and yellow fever. In the last years of the nineteenth century SIR PATRICK MANSON and SIR RONALD ROSS demonstrated the connexion between mosquitoes and malaria; Howard showed that flies may carry the germs of typhoid from manure heaps to human food; WALTER READ, an American army surgeon, demonstrated the connexion between mosquitoes and yellow fever.

Such biological discoveries have probably saved thousands of human lives and untold suffering and degeneration.

MOSQUITOES AND MALARIA. The life-history of the mosquito —egg → larva → pupa → two-winged adult insect—is told on p. 312.

It is the female mosquito, a blood-sucking external parasite, that spreads malaria. This disease is caused by a unicellular organism, simpler even than an amoeba in structure, which lives in the red blood-corpuscles of the infected person. When such a person is bitten by a mosquito the insect imbibes the parasite as well as the blood of its victim. The malarial organism goes through a complicated series of changes within the mosquito, being parasitic on it. It multiplies there, eventually reaching the insect's salivary glands. Now, when it feeds, the mosquito will inject a drop of fluid from these glands into its prey. The parasite is thus passed into the blood of the victim, and a new infection is started. Hence, whenever an infected female mosquito bites an uninfected human subject, it will in all probability set up the disease.

CONTROL OF MALARIA. It will be at once obvious to the reader that directly this life-cycle became known the disease could be brought under control. The methods of attack consist in:

i. Drainage of swamps, covering of exposed stagnant water (e.g. rain-water barrels), &c.
ii. Spraying swamps, &c., with paraffin so that the water becomes covered with a thin film of oil.
iii. Encouraging fish, &c., which live on mosquito larvae.

All these methods aim at destroying the mosquito larvae. Further, since mosquitoes cannot fly far:

iv. Separating infected from uninfected people.

v. Careful screening of houses, suitable clothes, mosquito nets, and all measures by which bites are avoided. It is hoped that a day will come when the tropical housewife will be as ashamed of mosquitoes in her home as is the housekeeper of more temperate climes of the presence of fleas.

By these and other similar precautionary measures malaria, yellow fever, hookworm disease, sleeping sickness, and many other dread diseases of the tropics are gradually being brought under control (cp. p. 519).

QUESTIONS ON CHAPTER XVI

1. Explain carefully the essential difference in nutrition between the algae and the fungi, and briefly describe one example of each of these classes. (L.G.S.)

2. Give an account of the life-history of Mucor, including reference to its mode of nutrition. (C.W.B.)

3. Show how the work of bacteria assists in the maintenance of plant and animal life. (D.)

4. Give an illustrated account of the life-history of Mucor or any other named fungus. (C.L.)

5. State the main differences between the nutrition of animals and plants. Compare the mode of nutrition of Mucor or other fungus with that of an animal. (C.L.)

6. Write an account of the circulation of nitrogen in nature, with special reference to the part played by living organisms. (L.G.S.)

7. How is the nitrogen of the air brought into combination under natural conditions? Draw a diagram of the nitrogen cycle and discuss its importance. (Ox.L.)

8. How do (*a*) plants, (*b*) animals, obtain the element nitrogen which is essential for the building up of protoplasm? Explain how it is that the source of available nitrogen does not become exhausted.

9. From what sources and by what methods do living organisms get nitrogen? Give definite examples. (C.L.)

10. What biological reasons are there for the rotation of crops? (Ox. & C. J.B.)

11. Describe the means of propagation of any parasitic mould or mildew, and its method of infecting its host. Name the parasite you select and its usual host. State briefly in what respects the parasite differs, in its mode of life, from a green plant, and in what respects it resembles an animal parasite such as ascaris. (L.G.S.)

12. Describe the structure and reproduction of any mould or mushroom. Point out in what respects its nutrition differs from that of a green plant. (B.)

13. Give an account of the circulation of carbon in nature, and describe simple experiments which may be performed to illustrate the facts. (L.G.S.)

14. What is a saprophyte? Give a careful account of any saprophyte you have studied, and compare its mode of nutrition with that of a typical parasite. (L.G.S.)

15. What is a parasite? How does a parasite differ from a saprophyte? Give an example of each, with a very brief account of its mode of life. (L.G.S.)

16. Compare the method of nutrition of a simple alga such as Spirogyra with that of a simple fungus such as the yeast plant. In what kind of places would you look for each in nature? (C.L.)

PART IV
SENSITIVITY AND CO-ORDINATION

CHAPTER XVII
REGULATION AND SENSITIVITY. THE NERVOUS SYSTEM OF INVERTEBRATE ANIMALS

THE NERVOUS SYSTEM. We have seen that food-getting is the first task of every animal; somehow or other it must get food or perish. We know that it cannot, as a rule, expect food to come to it, but must go out and actively seek it. Hence an animal is a more active creature than a plant; it is locomotory, not sedentary; a food-user, not a food-maker. The higher animal has a body of complex structure with much specialization and division of labour between its various parts. This specialization makes some method of co-ordination essential, so that its many organs may work in unison. Such co-ordination is the work of the nervous system, and of definite sense organs which make that system aware of events taking place in the outside world. Eyes and ears, for example, 'tell' the brain what is happening outside the body, warn the animal of danger, and guide it in its search for food.

We turn now to examine the nervous system in a few typical animals. As we ascend the scale from the simpler to more complex types, we find an increasing elaboration of the mechanism, such as was revealed by our study of digestive organs. The nervous system shows every transition, from the mere occurrence of certain specialized nerve-cells scattered irregularly among the other cells of the body (cp. Fig. 33) to the complex structure of the human brain, spinal cord, and nerves, with the accompanying sense organs.

NERVE-CELLS. What are the special features of nerve-cells? They are always cells with large nuclei but of quite indefinite shape, for from the main body of the cell a number of fine outgrowths of the protoplasm, called dendrites, are given off

(cp. Fig. 33). These pass between one nerve-cell and another, so that they are all linked together by a network of protoplasmic threads; hence a stimulus which affects any one of the cells can be quickly transmitted to every other member of the system.

In the higher animals the nerve-cells take the form of *neurons* (cp. Fig. 6 D). Such cells have, in addition to the dendrites already described, a much longer process called an *axon* (certain cells may have more than one axon). A nerve is simply a bundle of these axons.

Let us now study the arrangement of the nerve-cells in certain selected animals.

ANIMALS WHICH HAVE NO NERVOUS SYSTEM. To be sensitive to stimuli is one of the most characteristic properties of protoplasm, and in the simplest animals, as in all plants, there is nothing more than this. They have no specialized apparatus for receiving the stimulus or for passing it on from one part of the body to another. An amoeba can perform movements of locomotion, and is vaguely sensitive to its immediate environment. It can distinguish between certain stimuli, for it will ingest a tiny diatom, but not an inorganic particle of similar shape and size. Yet it possesses no sense organs and no nervous system. The whole of its protoplasm is diffusely sensitive to various stimuli and capable of making certain simple responses to them.

A DIFFUSE NERVOUS SYSTEM. In some animals we find nerve-cells scattered among the other cells of the body; Hydra has reached this stage of development (cp. p. 147). These cells are connected by their dendrites both with one another and with the body-cells, especially with certain sensory cells in the ectoderm, and by means of this network of protoplasmic connexions stimuli are rapidly conducted from one part of the body to another (cp. Fig. 33).

Hydra feeds largely on water fleas (Daphnia), living creatures which can move very quickly, as you will find if you try to catch one in the aquarium. The tentacles of Hydra, the nematocysts with their whip-like lassos which are shot out at the 'flea' (cp. Fig. 33), the movements of the whole body by

which the food-capturing apparatus is directed at the victim—all these must work in harmony if so active a creature is to be captured. Further co-ordination is necessary for its digestion; enzymes must be secreted at the right moment, and so on. In short the Hydra, small animal as it is, is capable of complex activities in which all parts of its body act in concert, and its network of nerve-cells, with protoplasm specialized to transmit stimuli, makes for rapidity and ease of combination.

A CENTRALIZED NERVOUS SYSTEM. In the higher animals we no longer find scattered nerve-cells; they are grouped together to form a central nervous system, from which bundles of axons (i.e nerves) pass out to more distant parts of the body. Just as an army is controlled from head-quarters, so that the movements of all its units can be properly co-ordinated, so the animal body is controlled by the central nervous system. An army uses telephone wires as one means of communication between the head-quarters staff and the units in the field. In the animal body nerve-fibres represent the telephone wires, and impulses are continually passing to and fro along these fibres between the central nervous system and the body-cells. The activities of the body are thus controlled and can all be directed to the accomplishment of some particular purpose.[1]

This method of control is most highly developed in vertebrate animals. Their central nervous system consists of brain and spinal cord, from which nerves pass to every organ of the body. Some of the nerve-fibres carry impulses outwards from the central nervous system to the other organs, others carry them from those organs *to* the central nervous system, for, unlike the telephone wire with which we have compared it, a nerve-fibre does not conduct impulses in both directions. We shall return to this subject in the next chapter (cp. p. 220).

THE NERVOUS IMPULSE. What is it that travels along the nerve-fibres in this way; what corresponds to the electricity in the telephone wire? This is a question to which we can, as yet, only give an imperfect answer. By suitable experiments the impulses can be timed. They move quickly, though not as

[1] There is also a system of chemical control by means of hormones. This is discussed more fully on p. 225.

quickly as an electric current, the rate being about 80 miles an hour in the frog, over 200 miles an hour in man.

But what travels along the fibre we do not know. We know that the fibre produces more carbon dioxide as a result of the passage, and so we may conclude that its rate of respiration is increased (cp. p. 265). We know also that certain electrical effects accompany the passage of an impulse, and that minute amounts of heat are liberated. These electrical effects can be amplified by an arrangement similar to that used in a wireless set, so that each impulse passing along the nerve causes a 'cracking' noise in the loud-speaker. By this method investigators have learned that on the *intensity* of a stimulus (i.e. whether it is strong or weak) depends the number of impulses passing per second along the nerve-fibre. Strong pressure on one touch organ, for example, will cause a large number of impulses to pass; a very light contact gives rise to far fewer.

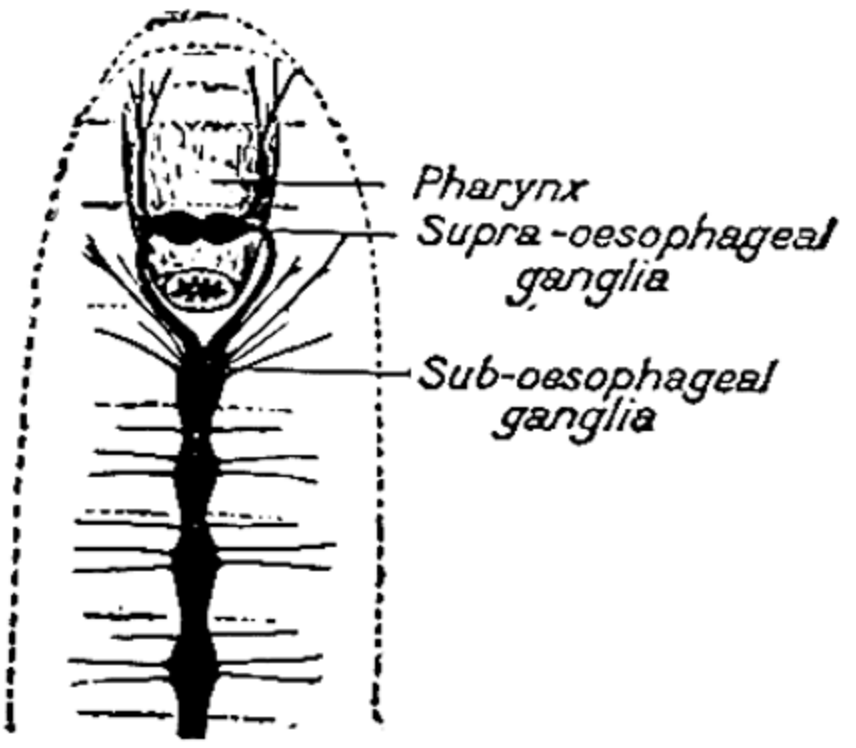


FIG. 53. Nervous system of earthworm (anterior portion only shown)

Our knowledge of nervous action is rapidly growing, but the exact nature of the nervous impulse still eludes us.

THE CENTRAL NERVOUS SYSTEM IN INVERTEBRATE ANIMALS. In many of the higher invertebrates, e.g. many worms, insects, crustacea, &c., the nervous system is formed on the same plan. It is always ventral in position, and consists of a double chain of ganglia (swellings containing nerve-cells), linked together by nerve-fibres (cp. Figs. 36 and 86). From the ganglia fibres also pass out to the various organs of the body; these bundles of fibres form the peripheral nerves. Such a system is shown in Fig. 53.

Exercise. Examine and draw a dissection of an earthworm in which the nervous system has been displayed. We notice:

(*a*) A pair of ganglia, called cerebral or supra-oesophageal ganglia,

placed above the alimentary canal, i.e. dorsal in position, and at the head end of the body.

(*b*) Two nerves (commissures), which surround the pharynx.

(*c*) Two ganglia into which these pass; these sub-oesophageal ganglia lie just underneath the anterior end of the pharynx.

(*d*) A double cord of nervous tissue, which runs the whole length of the body in the mid-ventral line and has a pair of ganglia in each segment.

(*e*) Three pairs of peripheral nerves, which pass from the central cord to the various organs in each segment (cp. Fig. 53).

Exercise. Examine and draw a dissection of a cockroach in which the nervous system has been displayed. Observe:

(*a*) The large supra-oesophageal ganglia—sometimes called the 'brain'. From these nerves pass to the eyes, the antennae, &c.

(*b*) Two commissures surrounding the pharynx.

(*c*) Two sub-oesophageal ganglia.

(*d*) The double ventral cord of nervous tissue, which, just as in the earthworm, runs nearly the whole length of the body. There are nine ganglia, corresponding to the first nine segments behind the head, i.e. three are thoracic, six abdominal.

THE NERVOUS SYSTEM OF INVERTEBRATES. We see the great similarity in general plan between the nervous systems of the earthworm and the cockroach. This double ventral cord of nervous tissue which is so characteristic of the higher invertebrates affords a very strong contrast with the dorsal, hollow tube of nervous tissue found in vertebrate animals.

SENSE ORGANS IN INVERTEBRATES. Earthworms have no obvious sense organs, yet they react quickly to light and to vibrations. They probably have some sense of taste and smell (cp. p. 229). All such stimuli are transmitted from sensory cells in the epidermis to the central nervous system through the fibres of the peripheral nerves.

Many invertebrates, however, have more obvious sense organs than has the earthworm. On the head of the cockroach, for example, we observe a pair of large, compound eyes, each segment of which can form an independent image (cp. Figs. 35 and 64). On the antennae there are simple organs of touch and smell (cp. p. 229).

Many insects are active and 'intelligent' creatures. Bees,

ants, butterflies—what different and highly skilled tasks these creatures perform, efficiently, and apparently without previous training (cp. Chapter XXXVI)! All such activities are controlled and directed by means of a nervous system of the type described, aided by special sense organs which inform the nervous system of events in the external world.

We turn now to the nervous system of vertebrates, to brain and spinal cord, and to those specialized sense organs with which we are already familiar, since we ourselves possess them.

QUESTIONS ON CHAPTER XVII

1. What is a nerve-cell, and what are its functions? Describe and give diagrams of a nerve-cell of (*a*) Hydra, (*b*) a vertebrate animal.

2. Describe how Hydra moves from place to place, and how it obtains and digests its food. Explain how these various activities are co-ordinated.

3. Describe the nervous system of the earthworm. What do you know of (*a*) the way in which this animal moves, (*b*) its reaction to stimuli? Point out what evidence there is, in its method of locomotion, of co-ordination between the various parts of its body.

4. How far can it be said that there is a differentiation of parts or organs in Amoeba and Hydra? Compare these two types in this respect. (C.L.)

5. In what ways is a hydra more specialized than an amoeba? (Ox.L.)

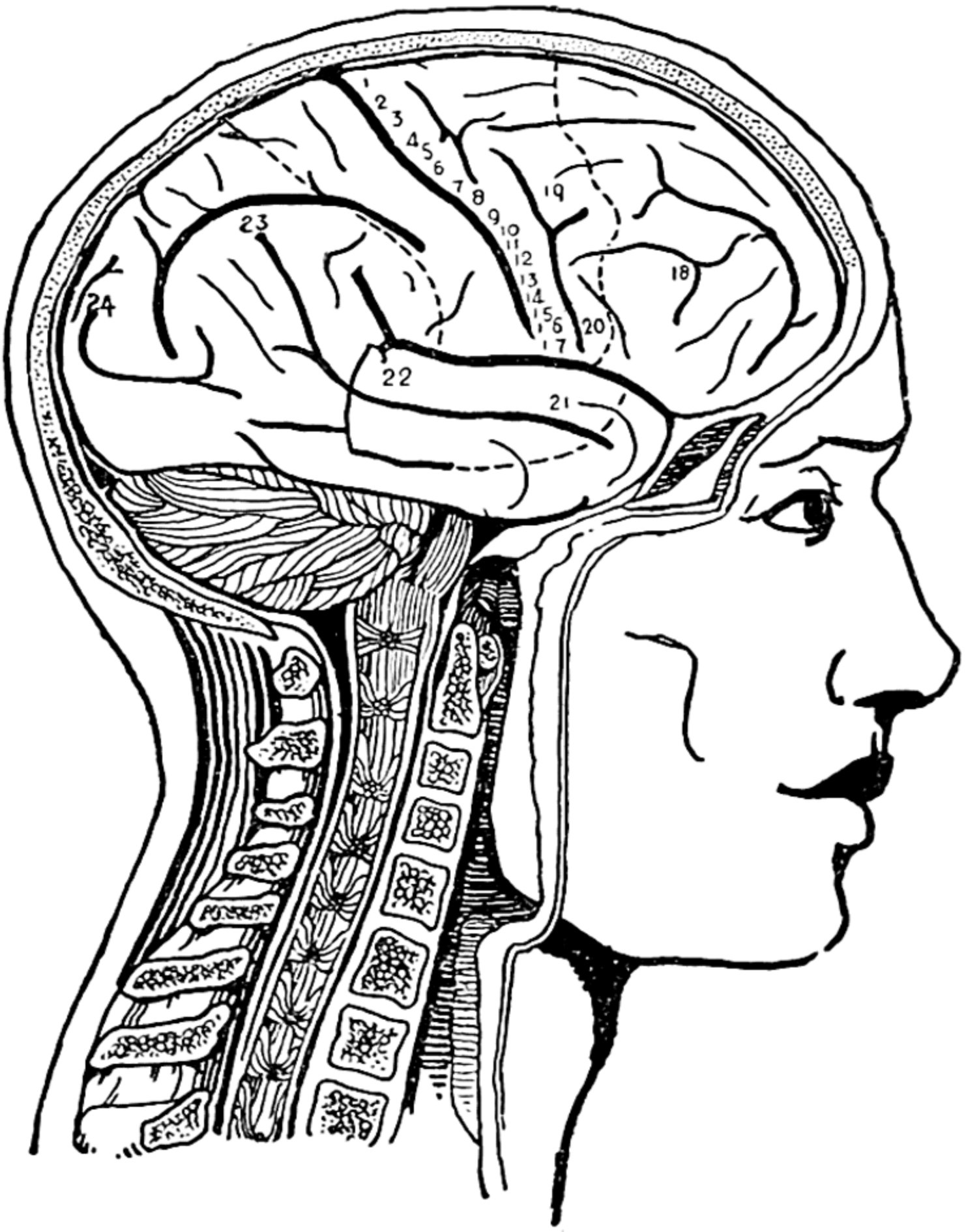


FIG. 54. Diagram of the human brain *in situ*, viewed from one side. The cerebral hemisphere (only one is visible) is white, the cerebellum coarsely shaded. The medulla is continued into the spinal cord. Other parts of the brain are concealed by the large cerebrum.

Motor areas. 1. Toes. 2. Foot. 3. Calf. 4. Thigh. 5. Abdomen. 6. Chest. 7. Back. 8. Shoulder. 9. Upper arm. 10. Forearm. 11. Wrist. 12. Fingers. 13. Neck. 14. Eyelids. 15. Cheek. 16. Jaws. 17. Lips. 19. Eyes. 20. Tongue.

Sensory areas. 21. Hearing. 24. Vision. 18. Co-ordination of speech muscles. 22, 23. Co-ordination of speech and thought.

(After Huxley and Starr)

CHAPTER XVIII

REGULATION AND SENSITIVITY (*continued*)

THE NERVOUS SYSTEM OF VERTEBRATE ANIMALS

ANIMALS POSSESSING A BRAIN. Many invertebrate animals—e.g. earthworms, cockroaches—have a central nervous system, but they have no real brain. In the vertebrate group the brain is the seat of all the higher faculties, such as memory, consciousness, will, and intellect. Further, these animals possess highly specialized sense organs, which give them very detailed knowledge of their surroundings. A hydra is sensitive to light, i.e. it distinguishes between light and darkness, and will move towards the light side of an aquarium which stands in shadow. But how much less perfect is this 'vision' than that of the reader of this page! Acute vision of actual objects in all their manifold variety, and the ability to follow such objects with the eye as they move, is one of the most valuable endowments which any animal can possess to equip it in the struggle for existence. Certain invertebrate animals have eyes, notably the insects (cp. Fig. 86). But the fullest development of this faculty of vision only comes with that co-ordination of eye and brain which is found among vertebrate animals. Eyes to see with, ears to hear with, a nose to smell with, and a mouth to taste with are among the many advantages possessed by the higher animals. These delicate organs are all controlled by the nervous system. Much of the control is automatic; every animal performs an enormous number of unconscious actions which continue during sleep, during a faint, even during the deep unconsciousness caused by an anaesthetic. Many activities, on the other hand, are conscious and deliberate; they are controlled by the will and influenced by reason and memory. Let us now see how all these actions, both the conscious or *voluntary* ones, and the unconscious or *reflex* ones, are directed by the central nervous system.

THE CENTRAL NERVOUS SYSTEM

BRAIN AND SPINAL CORD. In all vertebrates the nervous system is formed on the same plan. It consists of a hollow tube of nervous tissue forming the brain and spinal cord, the brain representing the specialized and highly developed anterior end of the cord.

The unit of which this system is composed is the neuron, a cell of very characteristic form (cp. Fig. 6 D). In the brain these cells lie chiefly near its surface, where they form the *grey matter* or *cortex* of the brain; the fibres (axons) are in the centre, forming the *white matter*. These conditions are reversed in the spinal cord, the neurons being internal, the fibres (white matter) external.

The whole structure is dorsal in position, and is encased in bone, the brain lying in the cavity of the skull, the spinal cord in the vertebral canal, a tube which penetrates all the vertebrae.

Exercises

Examine a dissection which displays the brain and spinal cord of a vertebrate animal; e.g. dog-fish, frog, rabbit, &c.

Examine any skulls which are available, e.g. frog, rabbit, dog, and man. Notice the brain-case (cranium), and the large hole (foramen magnum) at the base of the skull, through which, in life, the brain continues out into the spinal cord. Notice the increase in size (capacity) of the skull cavity as we pass from lower to higher forms.

Examine mounted skeletons of the frog, rabbit, and man, and notice the separate vertebrae which form the backbone (cp. Figs. 4, 127, 132, 135). Count the bones. There are 9 separate vertebrae and a long, unsegmented urostyle in the frog. The rabbit has some 45 vertebrae, of which the last 16 are very small; they form the tail. In man, there are 29 separate vertebrae, and four small vestigial ones which are fused together to form the tail-piece or coccyx (cp. Fig. 4).

Draw one of the lumbar vertebrae of a rabbit and label the bony centrum, on which the spinal cord rests, the much thinner neural arch arising from it, and the canal (vertebral foramen), formed by centrum and neural arch, through which the spinal cord passes.

THE BRAIN, ITS STRUCTURE AND FUNCTIONS. In the brain, which is the specialized anterior end of the spinal cord, we may distinguish three parts:

(*a*) The *fore-brain* and *cerebrum* (cerebral hemispheres).

(*b*) The *mid-brain*, whose roof consists of conspicuous *optic lobes*.

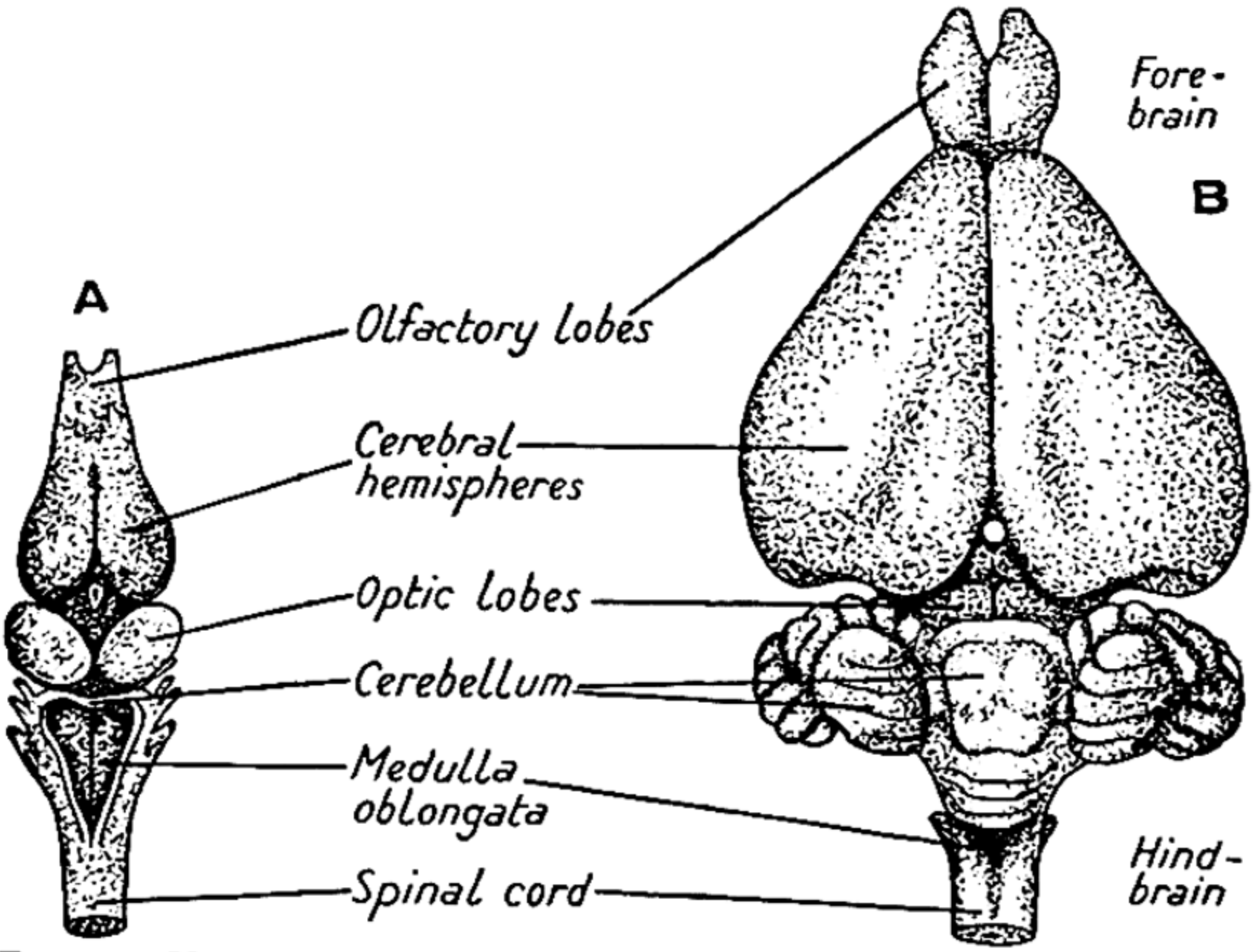


FIG. 55. VERTEBRATE BRAINS, VIEWED DORSALLY. A. Frog's brain. B. Rabbit's brain. (After Wiedersheim)

(*c*) The *hind-brain*, consisting of the *cerebellum* and *medulla oblongata*.

It has been found possible, partly by experiment and partly by medical observation of the effects of injury and disease, to find out a great deal about the functions of the various parts of the brain. Let us look at some of the most important of these.

THE CEREBRAL HEMISPHERES. In the lowest vertebrates this part of the brain is very poorly developed, but as we pass upwards it becomes increasingly important; the number of cells

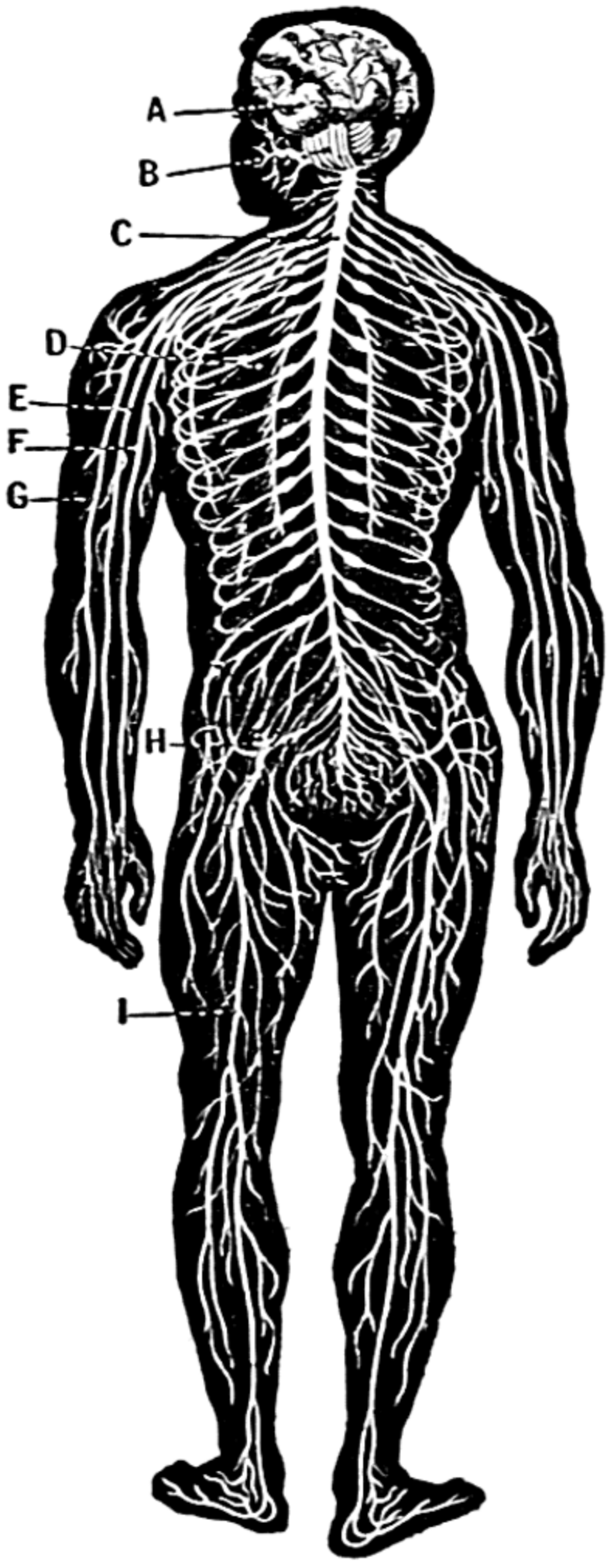


FIG. 56. Diagram showing the general arrangement of the brain, spinal cord, and some of the nerves in man. **A.** Cerebral hemisphere. **B.** Cerebellum. **C.** Spinal cord. **D.** Nerves of thorax. **E, F, G.** Nerves of arm. **H.** Nerves of leg issuing from spinal cord. **I.** Sciatic nerve of leg

in the cortex grows larger, the surface of the hemispheres becomes convoluted, so that more and more cells can be accommodated. In such animals the cerebral hemispheres are the chief co-ordinating centres: they are the site of all *voluntary actions* and of all *conscious sensation*. With them are associated *intelligence*, *memory*, and the *emotions*; in short, all those higher activities which distinguish man from the animal, and the higher animal from those lower in the scale. The less well developed the cerebral hemispheres, the less intelligent and teachable does that animal prove to be. Even in birds (whose lives are so largely governed by instinct), it is the primitive fore-brain rather than the cerebral hemispheres which controls many of their activities (cp. p. 503). The brains of man and of other mammals have been very intensively studied, and we can now locate various areas of the cerebrum which are concerned with special activities (cp. Fig. 54). Thus, there are motor areas which can be subdivided fairly accurately into those controlling the arms, legs, and so on; visual areas—if these are injured the creature is blind, although his eyes are perfect; speech areas, injury to which prevents the patient from speaking, and so on.

Of all the striking activities connected with the cerebral hemispheres, perhaps none is more important than the ability to learn from experience.

THE CEREBELLUM. The work of the cerebellum is not so well understood. One important function is apparently to co-ordinate movement, making possible concerted action between the various muscles. The human being has about five hundred muscles, and when we walk, skip, or jump, &c., we use most of them; to bring all their movements into harmony is the work of the cerebellum. The conscious impulse which makes us want to walk, skip, or jump originates in the cerebral hemispheres. They give the command; but, without the cerebellum to co-ordinate all the necessary movements by a large number of reflex actions, the impulse cannot be obeyed. When the human cerebellum is diseased the movements become jerky and clumsy, the walk uncontrolled, like that of a drunken man; even the speech is affected.

THE MEDULLA OBLONGATA. This part of the brain contains the nerve centres which automatically control respiration, circulation and the heart-beat, movements of the digestive organs and of swallowing, gland secretion, and many other unconscious activities.

In the structure of the brain one last feature must be noticed. It is divided into right and left halves, and many of the activities of the left side of the body are controlled by the right side of the brain, and conversely. This is because many fibres, in their course within the central nervous system, cross over from one side to the other. Hence pain, &c., on the right side of the body is recognized by the left side of the brain, and vice versa.

Exercise. Examine and compare the brains of a frog and a rabbit (or sheep). Notice the division, in both cases, into fore-, mid-, and hind-brain, also into similar right and left halves. Identify the cerebral hemispheres, the cerebrum (very small in the frog), and the medulla oblongata (cp. Fig. 55).

THE SPINAL CORD AND SPINAL NERVES. The spinal cord extends from the medulla oblongata nearly to the end of the backbone, passing through the bony vertebral canal. Like the brain, it consists of grey and white matter, but here the grey matter, which contains most of the nerve-cells, is internal. Bundles of fibres pass out from the cord, while others run in the cord itself, linking its cells with one another and with those of the brain.

The fibres passing out are a part of the *peripheral system.* They are very regularly arranged, corresponding in number to the vertebrae. (Both vertebrae and spinal nerves exhibit metameric segmentation; cp. p. 152.) Thus there are 31 pairs in man, about 40 pairs in the rabbit, only 10 in a frog. Each nerve arises from the grey matter of the cord by two roots, a dorsal and a ventral (cp. Fig. 57). Fibres of the ventral root carry impulses outwards from the central nervous system to the effector organs. These fibres are called *motor* because many of them control movement of muscle. The fibres of the dorsal root are *sensory*, and carry impulses from the receptor organs

(cp. p. 228) to the cells of the central nervous system. On each dorsal root there is an enlargement called a ganglion, which also contains nerve-cells.

THE CRANIAL NERVES. The peripheral nervous system of vertebrates consists not only of spinal nerves, but, in addition, of certain cranial nerves, of which ten pairs pass out from the

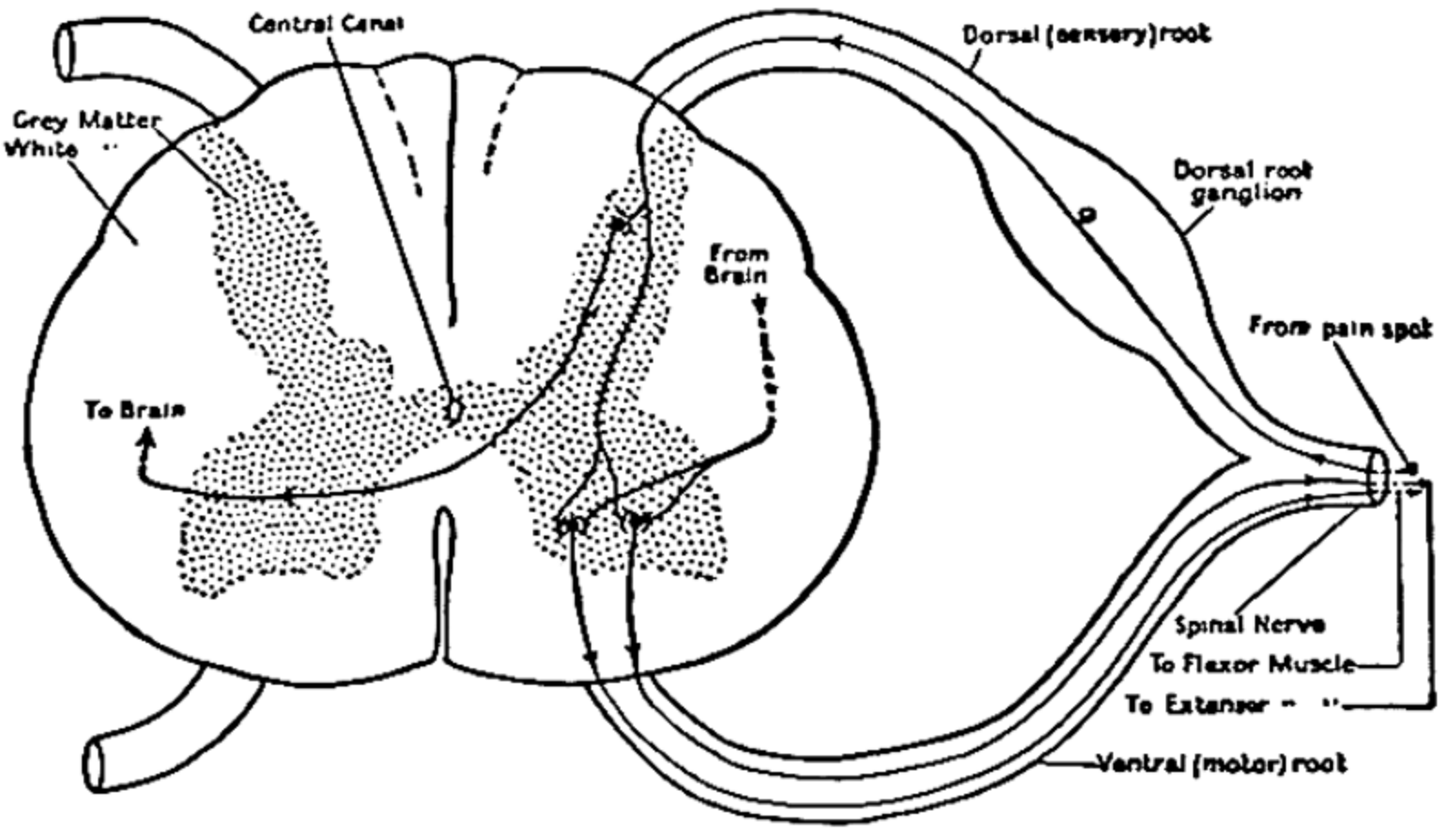


FIG. 57. Diagram showing the spinal cord (in transverse section) and the root, dorsal and ventral, of the spinal nerves. The nerve-cells are indicated as black dots, their fibres as lines. The grey matter of the cord is dotted

brain in all vertebrates (except mammals; these have twelve pairs). We number these cranial nerves in the order in which they arise (I–X), beginning from the front end. Many are connected with the organs of special sense—nose (smell) (1), eyes (2), ears (8). These nerves are purely sensory, conveying impulses to the brain from the three great sense-organs. Three (3, 4, and 6) are purely motor, controlling the muscles by which the eye is moved in its socket. The remainder (5, 7, 9), which are the nerves of face, jaws, neck, tongue, teeth, &c., are mixed, containing both sensory and motor fibres. The only cranial nerve which passes beyond the region of head and neck is the tenth, a mixed nerve, called the *vagus* or wanderer. It sends fibres to the heart, lungs, stomach, &c.

FUNCTION OF NERVES. REFLEX ACTION. Nerves are the paths along which rapid impulses pass to and fro between the body cells and the cells of the central nervous system. Some body cells are specialized to receive stimuli; these are the *receptor organs*, e.g. touch cells; others to respond to a stimulus; these are the *effector organs*, usually muscle or gland cells. The nerves link these organs through the central nervous system. For example, if we touch a hot poker, an impulse passes from each group of sensory receptor cells in the part of the skin thus stimulated, along the sensory fibres of the appropriate spinal nerve, into the nerve-cells of the ganglion, and thence, via the dorsal root, into the spinal cord (cp. Fig. 57). The cells thus stimulated now send an impulse outwards (along the motor fibres of a nerve) to the muscles of arm and hand. As the result of all these activities certain muscles contract, and we drop the poker before any impulse has reached the brain, and hence before we are conscious of the injury (cp. Fig. 58).

Such automatic and unconscious actions are called reflex actions.

CONSCIOUS ACTION. Meanwhile the effect of the stimulus has reached the higher centres of the brain, travelling through fibres in the cord itself. Directly it reaches these cells our behaviour becomes very different. We feel pain. Perhaps we tell ourselves how foolish we were not to realize that the poker was hot. Perhaps we expostulate with some one for leaving it in the fire. We may become anxious lest the noise of its falling has wakened the baby. We probably go off to find a bandage and the picric acid with which to assuage the pain.

All this is conscious behaviour and is much more elaborate and individual than is the simple reflex which made us drop the poker. Such reflexes we share with the animal, but no animal has learned to apply a bandage to an injured member. As we have already seen, this learning is one of the great functions of the cerebral hemispheres.

THE SIMPLE REFLEX ARC. Many of the movements of our body, e.g. the blinking of the eyelids, the alteration of the size of the pupil, coughing, sneezing, scratching an irritating spot, jumping when alarmed or surprised, are quite involuntary.

Such processes, which begin with an external stimulus and end in an involuntary action, e.g. a muscular contraction, are called reflex. In a simple spinal reflex the route by which the impulse travels is shown in Fig. 58. It is: Sense cell (receptor organ) → sensory nerve-fibre → neuron in spinal ganglion → connecting or association neuron in spinal cord → motor neuron

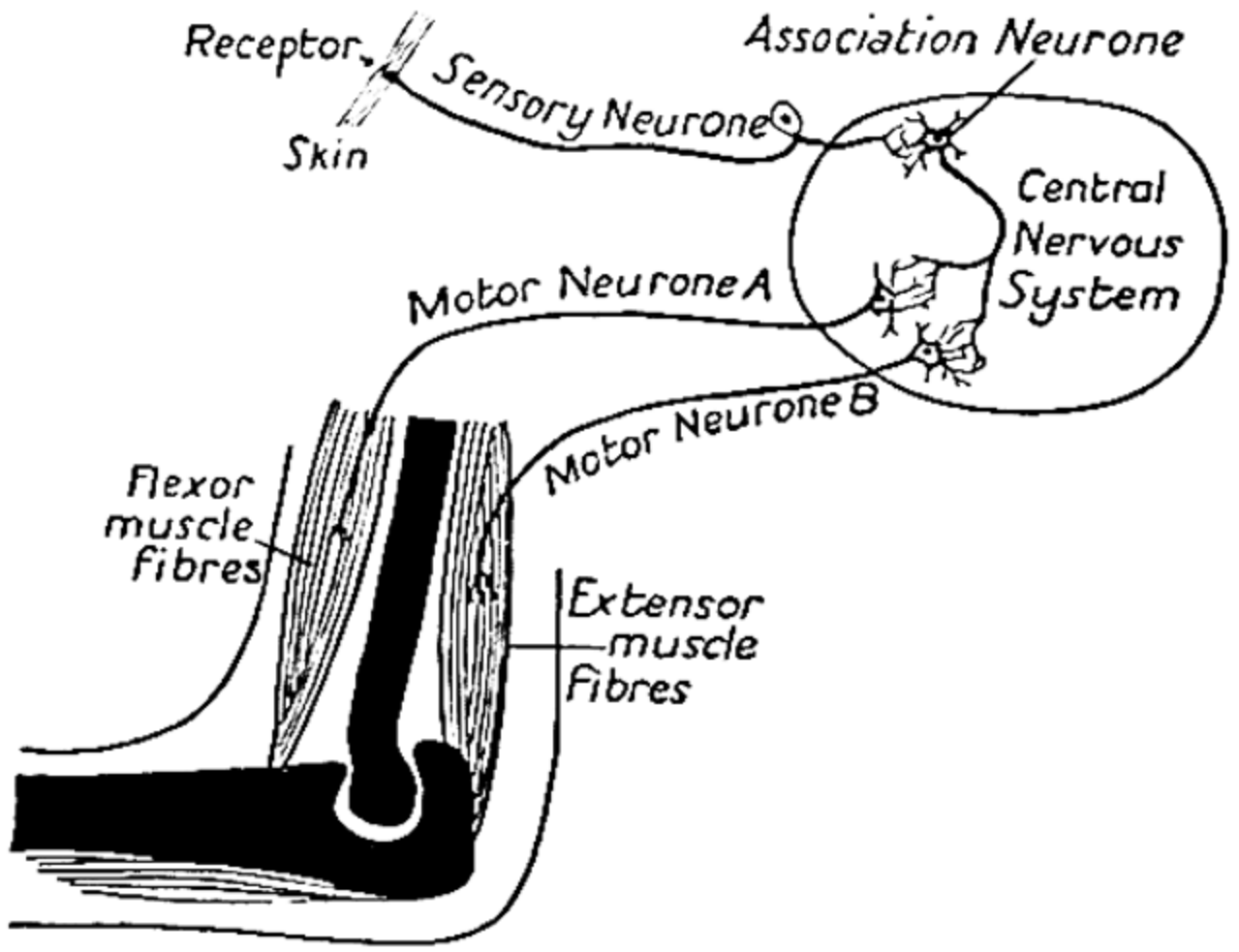


FIG. 58. Diagram to illustrate the course of the nerve impulses in a reflex action

in cord → motor nerve-fibre → muscle (effector organ). This figure also shows how the actions of two opposing muscles are co-ordinated in such a reflex, one contracting while the other relaxes.

Exercise. Sit with the legs crossed, one knee over the other, and the crossed leg hanging free. Tap yourself sharply just below the knee-cap. Quite involuntarily you jerk the leg outwards.

INBORN AND ACQUIRED (CONDITIONED) REFLEXES. This knee-jerk is a simple spinal reflex; it is quite automatic; the same stimulus always calls forth the same response. A great deal of the nervous control of the animal body is brought about by the linking up of simple reflexes. Many such reflexes are inborn. Many others are learned during the life of the animal.

A baby has to learn to walk upright, to talk, to write, &c. Watch an infant's first tottering steps, and compare its movements with those of a trained athlete—a runner, for example. Or compare the first clumsy attempts at writing with the beautiful penmanship seen in medieval manuscripts. From such examples we learn how great is the human capacity for learning to co-ordinate movements. Many things which we seem to do automatically have at first to be painfully learned, and constant repetition can make even the most skilful actions largely reflex. If we practise anything long enough, whether it be steering a bicycle or playing a Beethoven sonata, we find ourselves almost able to 'do it in our sleep', as we say. The cells involved have become so intimately linked that the impulses, once started, follow the accustomed paths almost automatically.

In these cases it must be the accustomed path. All the members of a school were asked to write out the words of a song which they were learning to sing for a special occasion. Several pupils were quite unable to *write* the words, yet knew them perfectly when allowed to sing them. You probably know many examples of the same phenomenon. Perhaps you must start from 1066 to find the date of one of the English kings. Or from the beginning of the multiplication table to find the value of 9×7? Considerations such as these make us realize how automatic oft-repeated actions may become. They become *habits*.

HABIT-FORMATION AND ITS IMPORTANCE. All through our lives we are acquiring new habits in this way. From what has been said it is obvious that we can influence their formation, inhibiting bad ones, and encouraging useful ones.

In this way we can control that delicate mechanism, our nervous system, which presides over so many of our bodily activities.

'Could the young but realize how soon they will become mere walking bundles of habits, they would give more heed to their conduct while in the plastic state. We are spinning our own fates, good or evil, and never to be undone. Every smallest stroke of virtue or of vice leaves its never-so-little scar. . . .

'. . . Among his nerve cells and fibres the molecules are counting it, registering it, and storing it up to be used against him when the next temptation comes. Nothing we ever do is, in strict scientific literalness, wiped out. Of course, this has its good side as well as its bad. As we become permanent drunkards by so many separate drinks, so we become saints in the moral, and authorities in the practical and scientific spheres, by so many separate acts and hours of work.' (James, *Psychology*.)

One of the many useful lessons that the study of biology is impressing on mankind is that we have considerable power of controlling our own development, both physical and mental.

THE AUTONOMIC NERVOUS SYSTEM

A DOUBLE NERVOUS CONTROL. Most organs of the vertebrate body have a double control. In addition to the central nervous system with its brain, spinal cord, and peripheral nerves, there is in these animals a second autonomic nervous system which is mainly motor. One part of this system consists of a double chain of *ganglia* containing nerve-cells, with nerves arising from them. Some of these nerves pass into the central nervous system and connect it with the autonomic system; others pass out to the viscera, to gut, glands, and indeed to most parts of the body. We have, as yet, very imperfect knowledge of the work of the autonomic system. It regulates the heart-beat, the size (calibre) of the arteries, the secretions of glands, and the movements of the gut, among its many other functions.

HORMONES. In addition to this nervous control there is, as has recently been discovered, a chemical method of co-ordinating the work of different organs by means of hormones (cp. p. 210). These are substances (internal secretions) which are formed by one organ, thrown into the blood-stream, and carried by it to other parts of the body, on whose activities they exert a powerful influence. For example, when food enters the duodenum, *secretin*, an important hormone, is formed by its walls. When in the ordinary course of the circulation this substance reaches the pancreas it stimulates that organ to increased activity; more pancreatic juice is formed and

digestion in the intestine is thus facilitated. Secretin also stimulates the flow of bile from the liver.

The action of other hormones is described on pp. 358, 387. New ones are constantly being discovered, and their great importance in the control of the body's activities is being increasingly realized.

THE CONTROLLING MECHANISM. A SUMMARY. We see that vertebrate animals possess very highly developed controlling and co-ordinating mechanisms, both nervous and chemical. Every nerve-fibre is connected with a nerve-cell, and if the fibre is separated from the cell it soon dies. Such fibres cannot transmit nervous impulses; the power of transmission depends on the fibre being alive.

The central nervous system, with its cells and fibres, is the seat of all those higher activities which we call mind.

QUESTIONS ON CHAPTER XVIII

1. Of what parts is the nervous system of a vertebrate animal composed? Give a short summary of the functions of the various parts. (L.G.S.)

2. What is a reflex action? Give a diagram of a reflex arc, and give three examples of simple reflexes, stating the exact path of the nervous impulse in each case. (L.G.S.)

3. Give some account of the structure and functions of the spinal cord.

4. Describe, giving fully labelled diagrams, the brain and spinal cord of a mammal, and state their function concisely. (L.G.S.)

5. Describe the structure of the brain of a mammal, and give a concise account of the function of its various parts. What do you know of the way in which we discover the functions of so complex an organ?

6. Explain how the various parts of a vertebrate animal are put into communication by the nervous system. (C.L.)

7. What are the special functions of a nervous system? Describe not more than *three* experiments illustrative of reflex action. (Ox. & C.)

8. What is meant by a 'reflex action'? Quote one example, giving a full account of the processes that take place in achieving it, and contrast such animal action with some one tropism exhibited by plants. (L.G.S.)

CHAPTER XIX

SENSITIVITY AND SENSE ORGANS

ORGANISM AND ENVIRONMENT. All through life there is a constant interplay between the organism and its environment, a constant adjustment of the organism to that external world from which its food, &c., is obtained. Sense organs are the intelligence agents by which animals (and even plants) receive stimuli from the external world. Such organs vary from simple unicellular structures, on the one hand, to complex organs like the human eye and ear, on the other. Our task is now to study these structures in more detail; each type is generally sensitive to one kind of stimulus only.

MUSCLE SENSE. With arms hanging down, shut your eyes; now put your hands out in front and bring your two index fingers together. You can do this very accurately and you know exactly what you have done. But how? Because of simple receptor organs in muscles, tendons, and joints. There are nerve endings on the sensory cells; these cells are stimulated by each change of position and the stimuli, passing along the nerves into the central nervous system, tell it which muscles you have contracted and which relaxed, what pressure there is in your various joints, and what bony surfaces are in contact.

Such generalized senses are among the most important in the whole body. They keep the central nervous system informed of what is going on in the outlying organs and so are essential to the co-ordination of muscular movements. They play an important part, for example, in the maintenance of the erect position.

Similar generalized senses, of which hunger and thirst are well-known examples, are probably present in all multicellular animals. They may be called *internal sense organs*, for they report on what is going on inside the body. *External sense organs*, on the other hand, make the creature aware of what is taking place in the outside world.

THE SENSE ORGANS OF THE HUMAN SKIN. In our skin we

possess many receptor organs for appreciating touch (contact), pressure, temperature, and pain. They are fairly simple structures, found all over the skin, though their distribution is by no means uniform. For temperature we have both hot and cold spots, the latter being about four times as numerous as the former.

Experiment 66. Take three basins of water, one as hot as the hand can bear, one lukewarm (about body temperature), and one cold. Put your right hand in the hot water and your left in the cold, keeping them there for a few minutes. Now plunge both hands into the lukewarm water. To the right hand it appears cool, while to the left one it seems warm.

We learn that our temperature sense is very relative, and it is common knowledge that some of our other senses are relative too. If, for example, we have been sitting in the dark for some time, the sudden switching on of a bright light may make us temporarily almost blind; we all know what trouble this 'dazzle' may cause to those who use the roads at night. Yet the same light switched on in daylight is hardly visible. Hence the old wives' tale that the sun puts out the fire.

Similarly, after eating sweets our tea may seem to be unsweetened; yet the same tea will taste quite sweet if taken after a savoury. Many other instances of this relativity of our sensations will occur to the thoughtful reader.

For touch there are touch spots in the skin, and the following experiment shows how much their distribution may vary.

Experiment 67. Take a pair of dividers, and adjust the points so that they are about 2 mm. apart. Press them tightly on the finger; two separate points are felt. Repeat this on the back of the neck; only one point can be felt. Now adjust the distance between the points, and find the minimum distance apart at which they can just be felt as two separate contacts. This distance is about 1 mm. for the skin of the finger-tip, about 7 mm. on the back of the neck.

There are far fewer touch spots in the skin of the neck than in that of the finger-tips.

This *sensitiveness to contact* is characteristic of all animals from Amoeba upwards; indeed even plant organs may respond to this stimulus (cp. p. 256). Most multicellular animals (meta-

zoa) possess sensory cells which receive the contact stimulus. Hydra, for example, has cnidocils (cp. Fig. 33); if one is touched it transmits the stimulus to the cnidoblast, the cell contracts, and the 'lasso' is ejected.

The earthworm has sensory cells scattered throughout its epidermis; they are specially abundant in the head region. From each a minute hair, which receives the contact stimulus, projects on to the surface of the body.

In animals belonging to the Arthropod group (e.g. crayfish, insects, spiders, &c.), which are covered externally by a hard shell or exoskeleton, the touch cells are more concentrated, being found only at certain definite points. These animals usually have one (insects) or two (crayfish) pairs of long feelers or antennae, which are organs of touch and frequently also of smell (cp. p. 230). We believe that ants, bees, and other social insects communicate with one another by means of this sense of touch, just as blind men do (cp. p. 491). Cells sensitive to contact may be found in other parts of the insect body, such as the joints of the legs, for example, and on the proboscis (e.g. cabbage white butterfly).

TASTE AND SMELL are two special senses possessed by most animals. The two are closely akin, both being chemical senses dependent upon the presence of particular substances in direct contact with the receptor organs. Even in man, much of what we call taste is really smell, and we may often drink the most unpleasant medicine without tasting it if we hold the nose until it is swallowed, i.e. if we prevent ourselves from smelling it. In these circumstances even an onion and an apple taste alike.

In experiments with the lower animals, and especially with invertebrates, it is not always possible to discriminate between these two senses, and we are often forced to speak of a 'chemotactic' sense. Darwin showed by experiment that worms will pick out onion and celery from other vegetable matter, exhibiting a marked preference for these substances. This suggests that they may have some sense of taste and also of smell, and similar experiments have demonstrated that these senses exist in many lowly forms of life.

Smell is very acute in many of the lower mammals. To the dog

the world of sense is pre-eminently a world of smells, and his natural instinct is 'to follow the scent' of the creature he pursues for food. It is also apparently very acute in many insects. In one experiment, for example, certain butterflies came for miles to the window of a room in which were some females of the species, which had been bred for experimental purposes by a Swiss scientist. They were so numerous as to arouse the attention of the passers-by, and yet there was no smell detectable by any human being.

In common with all mammals human beings have special

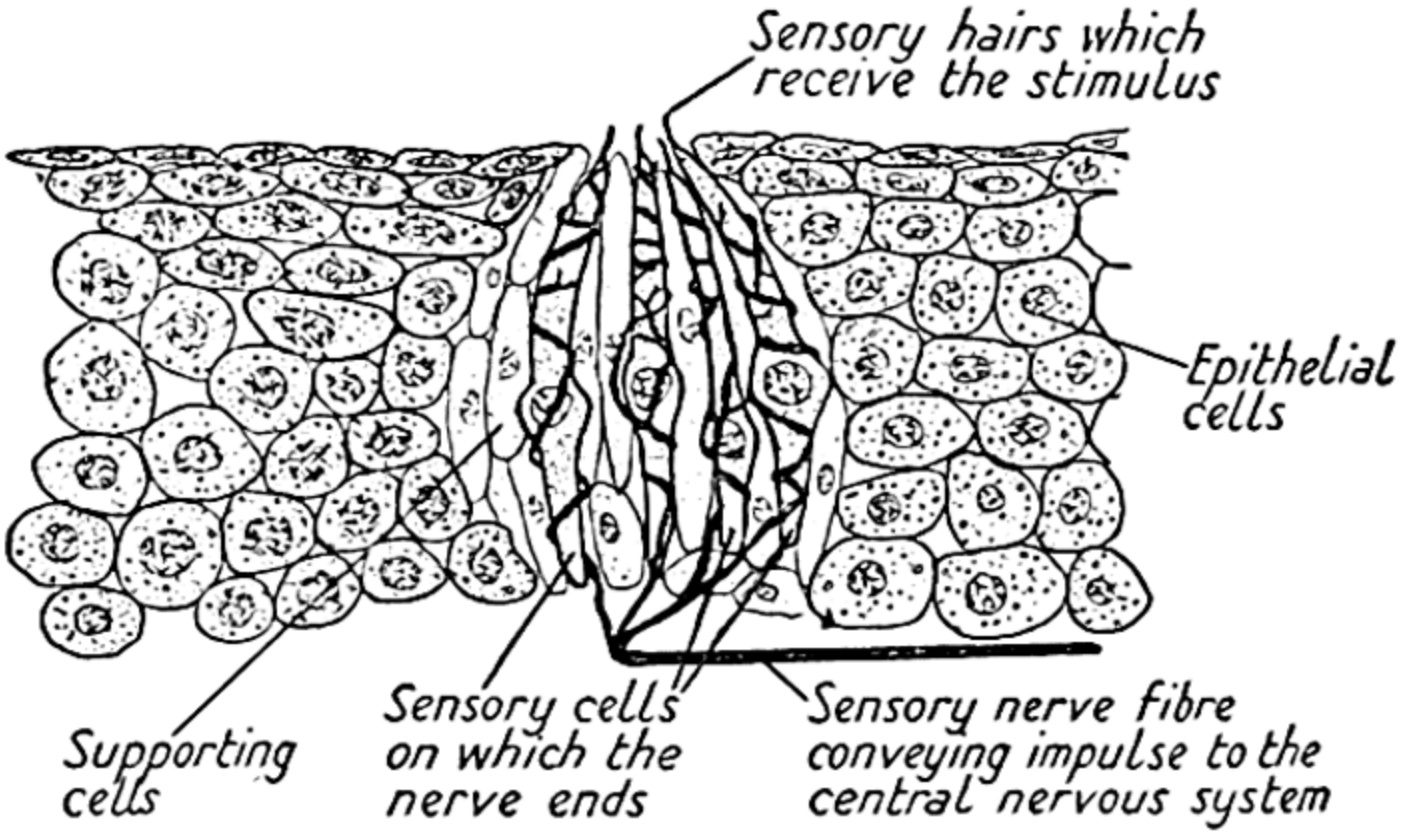


FIG. 59. The structure of a taste bud in a vertebrate animal

olfactory cells in the membrane lining the nose. They end in fine hairs, and if these are stimulated by certain vapours an impulse is set up which passes, by sensory nerve fibres of the olfactory nerve, to neurons in the brain.

For taste, mammals possess special *taste buds*, groups of cells in the lining of the mouth (cp. Fig. 59). Projecting from these cells into the mouth cavity are taste hairlets which come into direct contact with the food; a stimulus is imparted to them, an impulse passes from the taste cells to sensory nerve fibres which end on the bud, and is thence conveyed to the 'taste neurons' of the brain.

Experiment 68. Wash out the mouth with water, dip a glass rod into granulated sugar, and touch the tip of the tongue. No sensation of sweetness is experienced until the sugar has dissolved (taste cells are only stimulated by substances in solution).

Wash out the mouth again and touch the back and sides of the tongue. The *tip* is most sensitive to sweets. Repeat the experiment with something bitter, like quinine. The *back* of the tongue is sensitive to bitters.

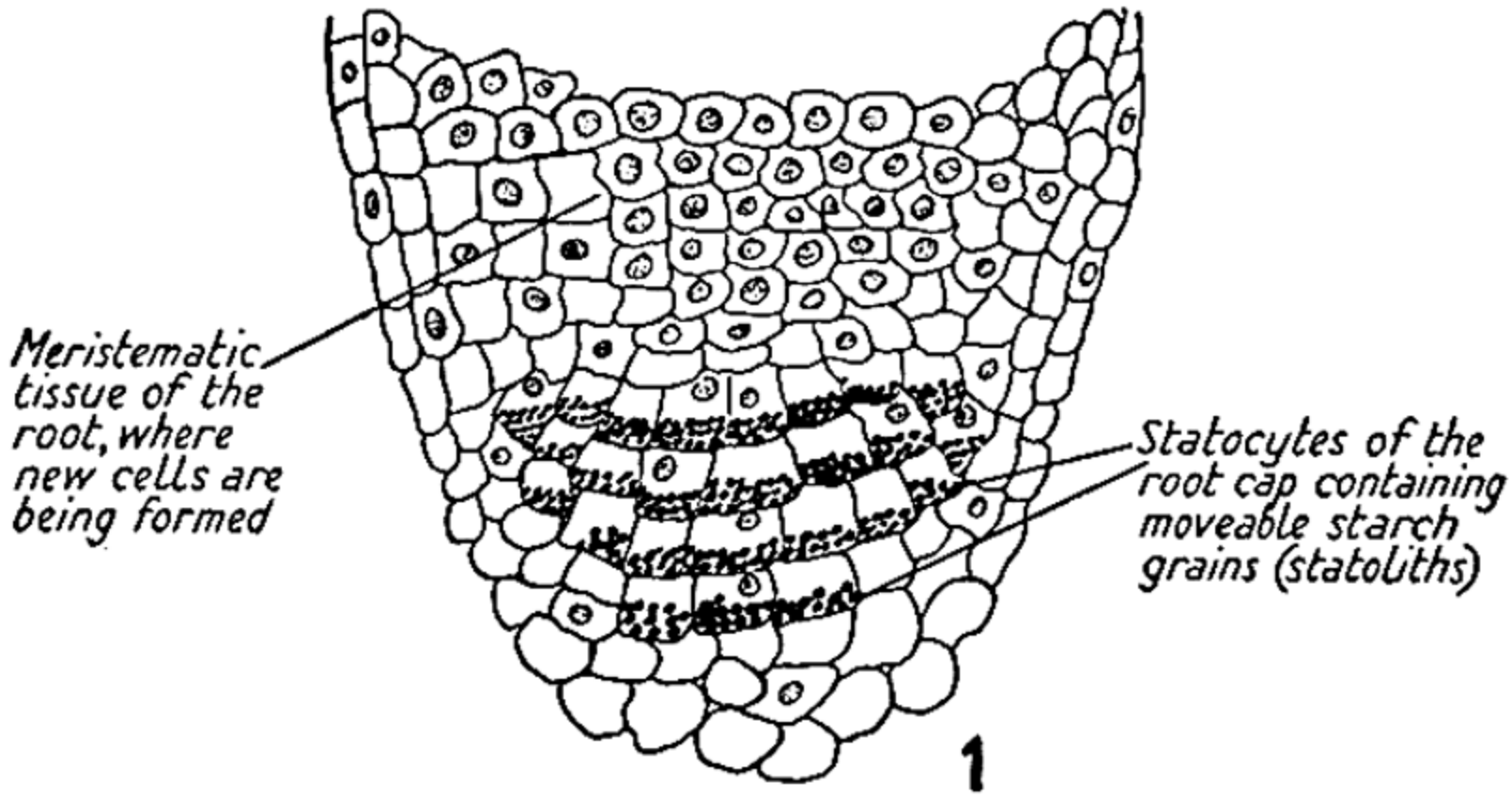


FIG. 60. THE REACTION OF A ROOT TO GRAVITY. 1. The root-cap and the gravity-perception organ. 2. A. Showing the effect of cutting off the root-cap on the root's response to gravity. B. The response in the same time of an uninjured root

There are four primary tastes, sweet, salt, sour (acid), and bitter, and by suitable experiments we can find special spots for registering each of these flavours.

GRAVITY-PERCEPTION ORGANS. Gravity is a force to which all living things, plants and animals alike, are exposed. They generally have some sense of their position in space, and many

possess special organs by which the stimulus of gravity is received.

There is a great similarity between all such organs, wherever they occur. Essentially a gravity-perception organ consists of two parts:

1. Tiny solid particles (statoliths or otoliths) which are free to move.
2. Sensitive protoplasm on which they impinge.

With every change in the position of the organism the pressure

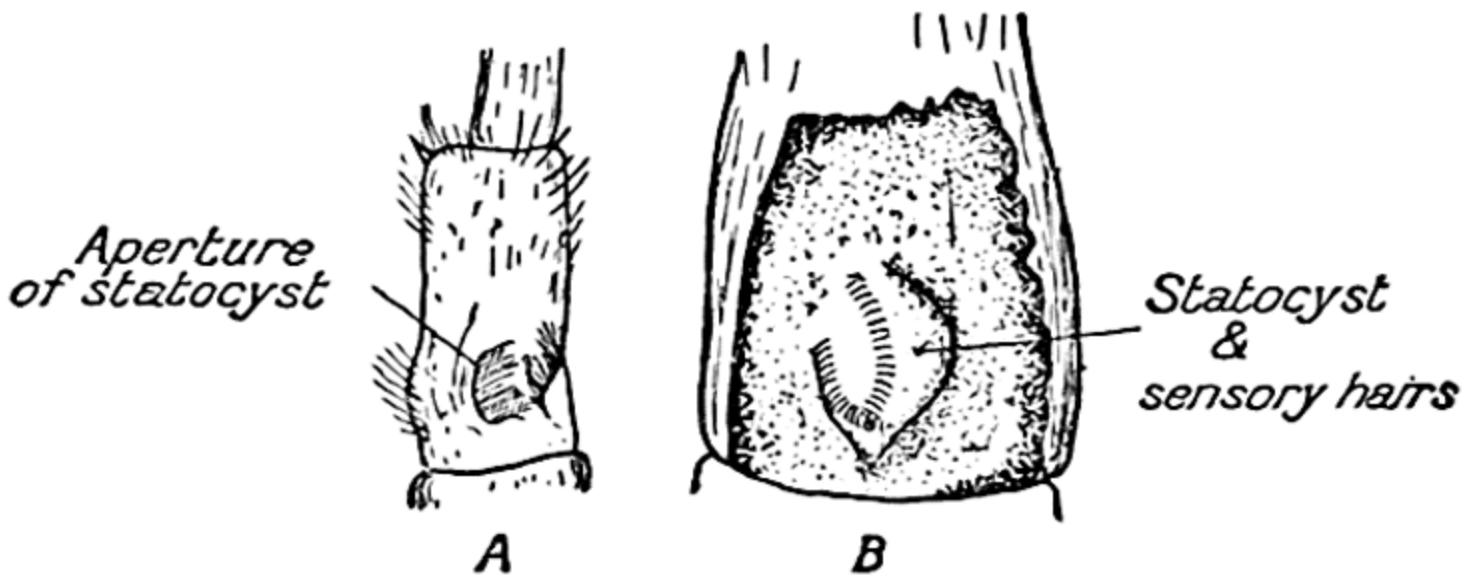


FIG. 61. STATOCYST FROM CRAYFISH. **A.** External view. **B.** Wall of leg-joint cut away to show the sense organ (more highly magnified than **A**)

of these solid particles falls on a different part of the sensitive protoplasm, so that each movement produces a new stimulus.

Even in plants (mosses, ferns, flowering plants, &c.) we often find groups of cells which contain movable solid bodies, usually starch grains (cp. Fig. 60). Experiments show that these 'statoliths' change their position with every movement of the plant, and such cells are believed to be real sense organs for perceiving the stimulus of gravity (cp. p. 264).

Most animals, from the Coelenterates upwards, possess organs for orientation which work on the same principle. In lobsters, crayfish, prawns, shrimps, for example, these organs take the form of little sacs called statocysts, which open to the exterior and are lined with sensitive hairs (cp. Fig. 61). The sac in some species contains grains of sand, placed there by the creature itself, and renewed after each moult (cp. p. 393). In many members of this Arthropod group there are two such

sacs, one on the base of each feeler (antennule). By a most instructive experiment it was definitely proved that these are true gravity organs.

Exercise. Study the effect of a magnet on iron filings before reading the next paragraph.

Experiment on Statocysts. A small prawn, Palemon, which had shed its shell and hence its statolith particles, was kept in absolutely clean water containing iron filings. Unable to obtain sand, it picked up some of these filings and put them into its statocysts. Now when a magnet was held above it, the filings were pulled upwards and the animal turned over on its back in a valiant endeavour to swim upside down. Whenever the magnet was moved the animal moved too. It reacted to the magnetic force as, in normal circumstances, it would have reacted to gravity, movement taking place whenever the statoliths (iron filings) were displaced from their normal position.

In vertebrate animals there is a gravity perception organ in the ear.

THE VERTEBRATE EAR.

The inner ear consists of an elaborate structure known as the membraneous labyrinth, which is embedded in bone. Between the bone and the labyrinth there is a fluid, the perilymph, while the labyrinth itself is hollow and filled with fluid, the endolymph.

The labyrinth (cp. Fig. 62) consists of: (1) A two-chambered organ, the cavities (saccule and utricle) communicating by a very narrow canal. (2) Three arching tubes, known as the semicircular canals, one horizontal, and the other two vertical in planes at right angles to each other. Each canal has at one end a slight swelling, the ampulla. (3) A spirally coiled cochlea, which contains the organ specialized to be sensitive to the sound waves by which the animal hears. This part of the internal ear, the hearing portion, is very imperfectly developed in the lower vertebrates, particularly in the fishes.

Let us first of all consider those parts of the ear which are *not* concerned with hearing: utricle, saccule, and semicircular canals are organs for giving the animal a sense of position (gravity perception) and for making it sensitive to changes in its velocity of motion.

The cavities of this part of the ear are filled with fluid and lined by a delicate membrane containing groups of sensitive cells, which are the actual receptor organs for stimuli due to gravity or to changes in velocity. There is a group in each ampulla and others in both utricle and saccule. These cells have long hair-like processes projecting into the endolymph, while they are connected below with nerve fibres of the eighth (auditory) nerve. Among these sensitive hairs, particularly in the utricle and saccule, are solid particles of calcium carbonate. These are the otoliths (or statoliths) of the ear, which are concerned with the perception of gravity. Stimuli caused by their movement are conveyed from the receptor organs to the central nervous system, and these stimuli make the animal aware o. its position in relation to the vertical. (Other sense organs help in this task, notably the eyes.)

The semicircular canals are more concerned with changes in the velocity of motion, whether a speeding up or a slowing down. If you sit blindfold on a roundabout, it is by stimulation of the sensory cells in the ampullae of the semicircular canals that your brain becomes aware of the direction and velocity at which you are whirling. The stimulus is caused by the fluid in the ampullae, which lags behind or goes ahead according as the velocity is increasing or decreasing.

To sum up, this part of the internal ear is concerned with the sense of position (gravity perception) and with changes in velocity and direction of movement. It is by a chain of reflex actions, initiated by stimuli coming from this portion of the ear, that a cat dropped upside down from a height rights itself in mid-air. Violent stimulation of these sensory cells leads to giddiness, which, as we all know, may be so great that we cannot stand. Now such a condition would be fatal to an airman and so they are subjected to special tests; for example, they may be strapped in a chair and spun round in various directions, to see whether they can retain their power of control. If they become helplessly giddy they are obviously not suitable people to pilot an aeroplane. Stimulation of these cells is probably the primary cause of sea-sickness.

The auditory organ. The ear, as we all know, is also an organ for hearing. The cochlea (cp. Fig. 62) is the ultimate receiving station for sound waves. It contains a delicate membrane, on which there are some 16,000 nerve endings, all branches of the

auditory (VIIIth cranial) nerve. Nevertheless, it is only sensitive to vibrations of certain frequency, the limits for us lying between 16 and 40,000 vibrations per second. These limits are not the same even for all mammals; a dog will respond to

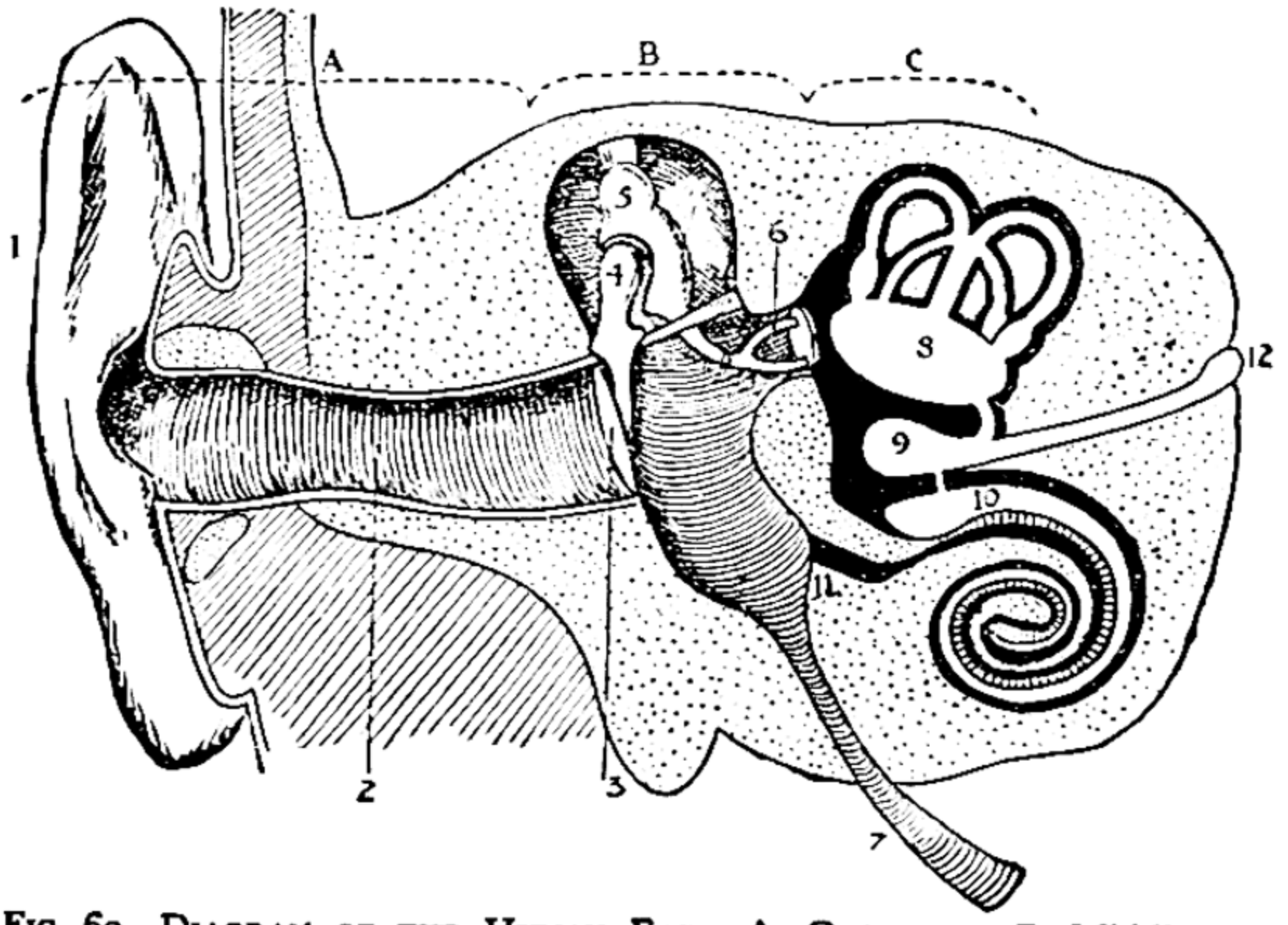


FIG. 62. DIAGRAM OF THE HUMAN EAR. **A.** Outer ear. **B.** Middle ear. **C.** Inner ear. 1. Ear-trumpet (*pinna*). 2. Passage of outer ear (external auditory meatus). 3. Ear-drum (*tympanum*). 4, 5, 6. Small bones which transmit vibrations to the 'window' (to the right of 6) in the bony wall of the inner ear. 7. Eustachian tube, a communication between the cavity of the middle ear (which contains air) and the mouth. 8, 9, 10. The membraneous labyrinth, containing fluid endolymph and lying in the fluid perilymph (black shading). Arising from 8 are the three semicircular canals. 10. The spiral cochlea, the organ of hearing

a whistle which we cannot hear. Some invertebrate animals, too, make, and therefore presumably 'hear', sounds to which the human ear is insensitive.

The middle ear. All sound is due to a wave motion, usually a wave motion in air, and the middle ear is specialized to receive such waves. It consists essentially of a stretched membrane, the ear-drum or *tympanum* (3, Fig. 62), on which the vibrations impinge. Attached to the inner face of this drum

there is, in mammals, the first of a chain of three little bones (4, 5, 6, Fig. 62) which transmit the vibrations from the drum to the endolymph and so to the cochlea. A narrow tube leads from the cavity of this middle part of the ear (7, Fig. 62) into the back of the throat (cp. Fig. 43). This tube—the *Eustachian tube*—ensures that the pressure of the air on the two sides of the ear-drum is kept equal. In spite of this protective mechanism the drum may be ruptured by a sudden explosion, such as that due to a large gun; in such cases the pressure is not equalized quickly enough.

The external ear. In addition to inner and middle ears we, in common with birds and other mammals, possess an external ear. This is a passage (2, Fig. 62) surrounded by bone, down which the vibrations travel till they reach the ear-drum. In birds the opening of the external ear is merely a round hole, but in mammals it is surrounded by a trumpet or pinna (1, Fig. 62). This serves to collect the sound and at the same time helps the animal to determine from what direction it is coming. Watch a horse or a rabbit and notice the use of the pinna. In man it is not movable, and he turns his whole head when a horse would only move his ears.

THE EARS OF VERTEBRATES. *A comparison.* It is most interesting to compare the ear of different groups of vertebrates.

In *fishes* it is an organ for gravity perception and for direction of movement, rather than for hearing. Its main parts are the membraneous labyrinth and semicircular canals. The cochlea is very rudimentary, and there is no middle or external ear. In the *frog and other amphibia* you will have noticed the tympanum on the side of the head, below and behind the eye (cp. Fig. 99). This is the ear-drum. A frog has an internal ear with a fairly well-developed cochlea, and a middle ear (but with only one bone, and not three, as in mammals, linking up the ear-drum with the internal ear). It has no external ear. This is only found in true land animals—reptiles, birds, and mammals.

EVOLUTION OF THE EAR. We learn once again that lesson which every comparison of living organisms imparts, that there is a gradual increase in complexity, a gradual specialization of structure, as we pass from the lower to the higher forms.

We speak of 'the gradual evolution' of the ear of the land vertebrate, and imagine that it has been derived from some simpler

structure, such as that still persisting in the lower vertebrates; an organ consisting of an inner ear only and not yet organized to receive sound waves which travel through air.

LATERAL-LINE ORGANS. Fishes (and some newts) have, scattered in their skin, organs whose functions are probably somewhat allied to those of the ear, serving for balance and for the perception of waves of low frequency ('hearing'), such waves as might be caused by the movements of other creatures through the water. These organs are found on the snout and sides of the head, and also down each side of the body, where they form the conspicuous 'lateral line'.

They consist of small pits, of small communicating canals, or, in the case of the lateral line, of one immensely long canal provided with a number of minute pores which open on the surface of the animal. All these structures are filled with mucus and contain groups of sensory cells, each group constituting a simple sense organ (neuromast). The sense cells have blunt processes which project into the mucus and which are the actual receptor organs, while internally they are connected with the end fibres of one of the cranial nerves (V, VII, or X).

It seems possible that the internal ear itself, in spite of its much greater complexity of structure and function, represents simply a specialized neuromast organ.

Exercise. Examine the head and dorsal surface of a dogfish, cod, or salmon. On the head are a number of minute holes, looking like pin-pricks arranged in some complicated pattern, while extending along each side of the body from head to tail is a dark streak which marks the lateral line. If you squeeze the animal in these regions mucus will exude at the pores.

SENSITIVITY TO LIGHT

THE EYES AND VISION. Sensitivity to light is a very general characteristic of living organisms, most plants and many animals being sensitive to it, although they have no eyes.

The first trace of an eye is seen in the tiny red eye-spot of certain unicellular organisms, e.g. Chlamydomonas. It is a far cry from this speck of light-absorbing pigment to the highly organized eyes found in some invertebrates (the insects,

for example), and in all vertebrate animals. We cannot in this book trace the development of the eye through all its many stages; that there has been a gradual evolution of the more complex mechanisms seems certain. Let us look at the highly organized eye of vertebrate animals.

THE VERTEBRATE EYE. The mechanism of our eye is very like that of an ordinary photographic camera. In any camera the essential parts are the lens which forms the image, and the sensitive surface (plate or film) on which this image is thrown. In most cameras there is also a focusing apparatus which enables us to obtain a clear picture of both near and distant objects.

Exercise. Students who have not already studied the action of lenses are advised to do some simple experiments, particularly with convex lenses, before they proceed to the study of the eye. Suitable ones are described in any text-book of elementary physics.

In the eye (cp. Fig. 63) the *retina* corresponds to the photographic film, and the eye, like the camera, has a lens. This throws an image on the retina which is upside down and right-side left. In a camera we change the focus by altering the position of the lens; in the eyes of bony fishes and of amphibia the same method of focusing is used. In man and other mammals the focus is changed by altering the curvature of the lens itself, this alteration being the work of the ciliary muscles (cp. Fig. 63). Another important part of the vertebrate eye is the *iris* (the coloured portion); this regulates the amount of light which enters the eye by altering the size of the *pupil.* You should observe its action in the eye of a friend (or of a cat—where the pupil narrows to a long slit).

The retina is a very specialized membrane which lines the inner surface of the eyeball. It contains sensory cells, called rods and cones, which receive the light-stimulus, and nerve endings to which this stimulus is then imparted. Impulses are thus initiated which pass to the brain through the optic nerve (cp. p. 221). By a well-known experiment we can show that, when the sensory (receptor) cells of the retina are absent, no vision is possible. The optic nerve itself is not sensitive to light, and, in the region where this nerve enters the eye to spread

out and form the nervous layer of the retina, there are no sensory cells. This point in the human eye is known as the

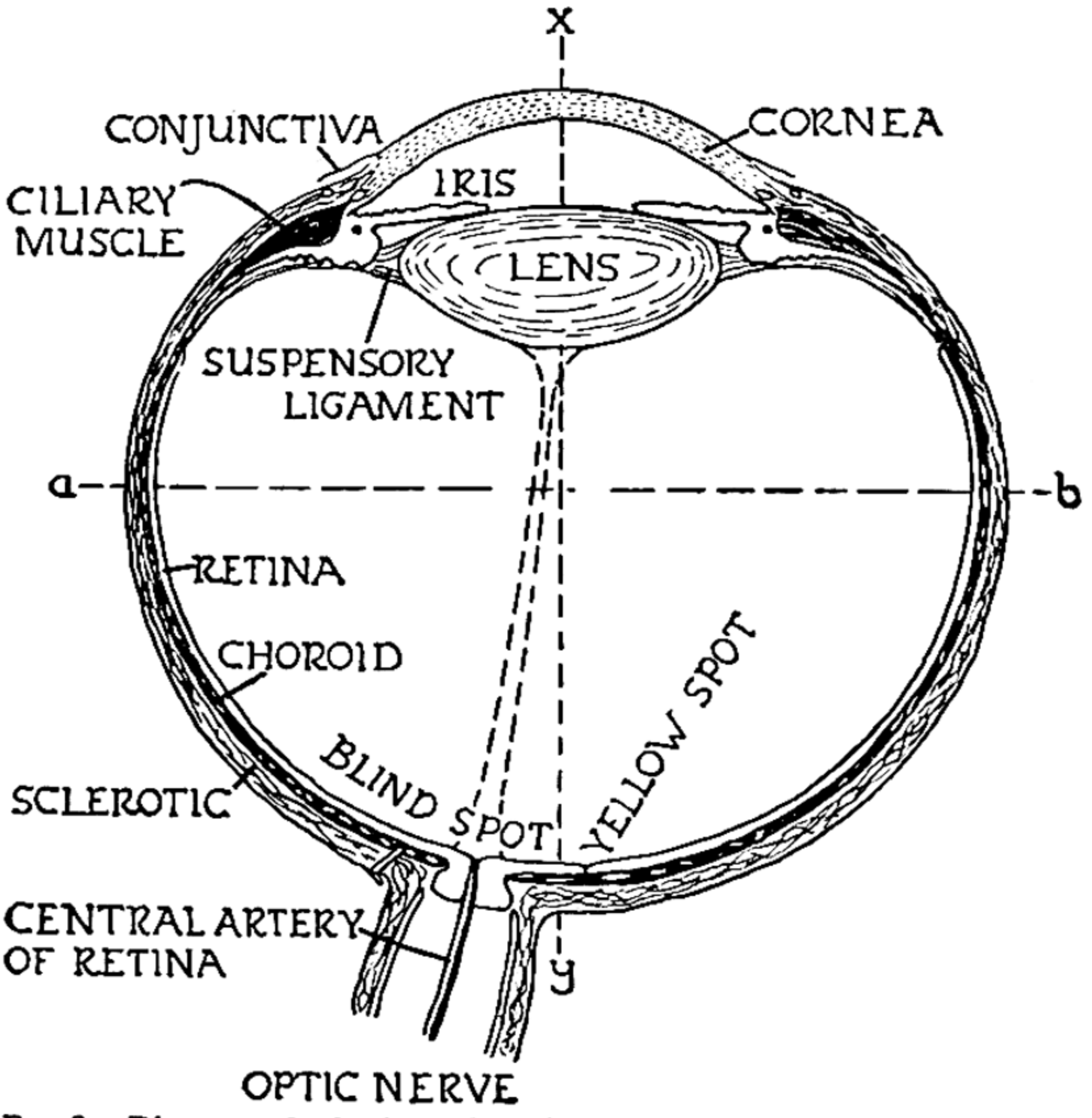


FIG. 63. Diagram of a horizontal section through the right eye of a man. The lens and iris separate the anterior chamber (filled with aqueous humour) from the posterior chamber (containing the jelly-like vitreous humour). The shape of the lens can be altered by the ciliary muscle pulling on the suspensory ligament

blind spot (cp. Fig. 63), for when light falls upon it no sensation is registered by the brain.

Experiment 69. To show the existence of the blind spot make a dot and a cross about 3 inches apart on a sheet of white paper, the cross being to the right. Now hold the paper about 1 foot away from

the eye. Shut the left eye, and keep the right eye fixed on the cross. As we move the paper nearer, there comes a moment when the spot disappears from view. Rays coming from it are now falling on the 'blind spot'.

Repeat the experiment, shutting the right eye and fixing the left one on the spot. The cross can now be made to disappear in the same way.

Figure 63 shows that the eye contains two cavities. The one in front of the lens is filled by a watery fluid, the aqueous humour; the one between the lens and the retina contains a transparent jelly, the vitreous humour.

Exercise. Obtain a fresh bullock's eye from the butcher. Notice the pupil, the aperture through which light enters; the iris, by which the size of the aperture is regulated; and the tough white sclerotic, with the transparent cornea in front—the whole forming the protective covering of the eyeball.

Open the eye with scissors and identify the lens, the dark-coloured retina, and the aqueous and vitreous humours. If a window is cut in the side of the eye the blind spot becomes apparent as a small whitish circle.

Such is the general structure of the eye in all vertebrates. Another interesting type of eye, into the study of which we cannot enter, is the compound eye seen in butterflies and many allied forms. You should carefully notice the external appearance of such eyes during your study of insects.

DEFECTS OF VISION. In the modern world we use our eyes for very delicate work, and this reveals many minor defects of vision. Some people can see distant objects clearly but cannot focus their eyes for near vision. Since the power of focusing diminishes with age this 'long sight' is generally a defect of middle life. Other people cannot focus distant objects—i.e. they are 'short-sighted'; these and many other defects may be corrected by suitable lenses, convex for long sight, concave for the short-sighted.

A defect of another kind is colour-blindness, which is fairly common among men. It is an inherited defect, usually passed on by a mother, whose vision is quite normal but who is the daughter of a colour-blind man, to her son. It is therefore chiefly a male defect; in such eyes the mechanism for discriminating between one colour and another is faulty. An analogous defect in the ear renders people 'tone-deaf'.

COLOUR VISION. The whole subject of colour vision is most interesting, and presents many as yet unsolved problems. If, for example, a disk is painted in the colours of the rainbow (red . . . violet), each colour is seen separately so long as the disk is at rest. But if it is rapidly rotated the eye does not distinguish the separate colours, but blends them so that the disk now appears white.

It is not necessary to blend all the colours of the rainbow to obtain this result. If a top which is painted half orange, half blue, is spun rapidly, the two impressions are fused and the top appears almost white. How does the eye achieve this effect? How different is the result if orange and blue pigments are mixed together! This blending produces a pigment which is green, not white. Many theories have been put forward to explain how colour is perceived, but none is entirely satisfactory.

In a dim light our sense of colour vanishes, and objects only differ in the *intensity* of their illumination, looking uniformly whitish, grey, or black. It may be that this is the only kind of vision possessed by many animals, even by certain mammals. It seems likely, for example, that dogs cannot distinguish colour.

COLOUR VISION IN INVERTEBRATES. Considerable interest attaches to the colour vision of invertebrates, especially the insects. Many flowers are insect-pollinated (cp. Chapters XXXIII and XXXIV). Such flowers are usually brightly coloured, and their colour is supposed to attract the insect. But can insects really distinguish differences in colour? Many attempts have been made to determine by experiment whether bees, for example, have a colour sense, and on the whole such experiments seem to show that they do distinguish certain colours. In all such investigations, however, it is difficult to be sure that different colours are seen. In many cases the results obtained might be due to differences in brightness (intensity). It is undoubtedly true that many creatures which have no sense of colour are sensitive to differences in light-intensity. Even plants react to light and carry out heliotropic movements (cp. Figs. 70 and 72).

ANIMAL TROPISMS. Many animals carry out tropic movements in response to light and other directive stimuli. These are movements of the whole body towards or away from the stimulus (cp. p. 246), the animal turning and adjusting its position so that its paired sense organs (e.g. two eyes, two antennae, &c.) are equally stimulated. Some animals, for example, are negatively heliotropic, moving away from the

light and always seeking the shade (e.g. earthworms, blow-fly larvae, crayfish). Others are positively heliotropic (e.g. the moths which flutter around a candle).

Experiment 70. To show the effect of light on the larvae of the blow-fly, place them (together with small fragments of meat) in a test-tube, one half of which is painted black. The larvae move away from the light—they are negatively heliotropic.

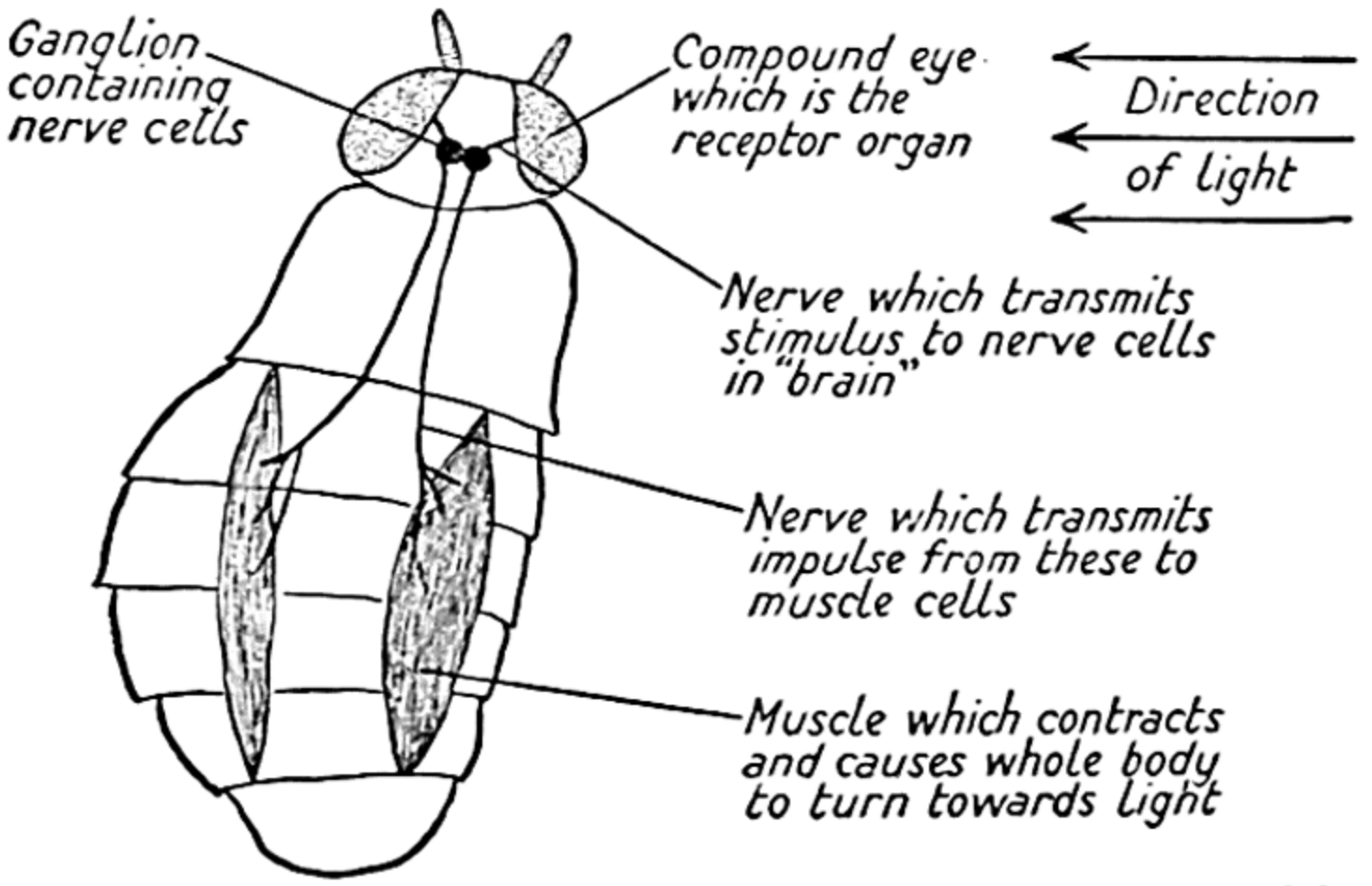


FIG. 64. Reflex action in an insect which moves towards light. (After Hogben)

Many animals exhibit a similar inborn obligation to adjust their bodies in a definite position with regard to some stimulus, and we now know something about the mechanisms underlying these responses. Experiments have shown that, when light falls more brightly on one eye of an insect than on the other, the muscles of one side are stimulated to contract (cp. Fig. 64). This causes a turning movement of the whole body, which is bent round until the two eyes are equally illuminated, when the creature moves straight on—towards the light if it is positively heliotropic (cp. Fig. 64), away from it if its reaction is negative.

These actions are purely automatic (reflex). No consciousness enters into them and, as we all know, they may make a creature fly even to its death.

QUESTIONS ON CHAPTER XIX

1. What do you understand by irritability? Give three examples of this phenomenon, one from the plant world, and two from the animal world.

2. Describe the ear of a mammal (or frog), and show how its various parts are specialized to perform different functions.

3. What do you understand by gravity? Describe two organs of gravity perception found in animals. Are there any similar organs in plants?

4. Give a large, labelled diagram of the eye of a vertebrate animal, as seen in section, and briefly describe the functions of its various parts. (C.W.B.)

5. 'Irritability' is one of the properties common to all living things. Explain the meaning of this term. How is the truth of this sentence shown in the behaviour of (*a*) a mould, (*b*) Amoeba, (*c*) a germinating seed, (*d*) a sweet-pea plant? (L.Matric.)

6. 'Sensitivity' or 'irritability' is one of the characters of all living things. Explain the meaning of these terms. How is 'sensitivity' or 'irritability' demonstrated in the behaviour of (*a*) a seedling and (*b*) a frog? Details of structure are not required. (Ox. & C.)

7. Give a brief account, illustrated by examples, of the responses made (*a*) by plants, (*b*) by animals, to various external stimuli. (L.G.S.)

CHAPTER XX

REGULATION AND SENSITIVITY IN PLANTS

FORCES DIRECTING THE PLANT'S GROWTH—TROPISMS. By observation and experiment we can easily show that plants, as well as animals, are influenced by stimuli coming to them from the environment. Particularly important are the stimuli which direct their growth and cause them to place their organs in definite positions with regard to the earth's centre. In our study of the growth of the bean seedling, for example (cp. p. 86), we found that the radicle grows downwards and the plumule upwards, no matter in what position the seed is planted. We are obviously dealing here with some directing stimulus, and we will now try to discover what these stimuli are.

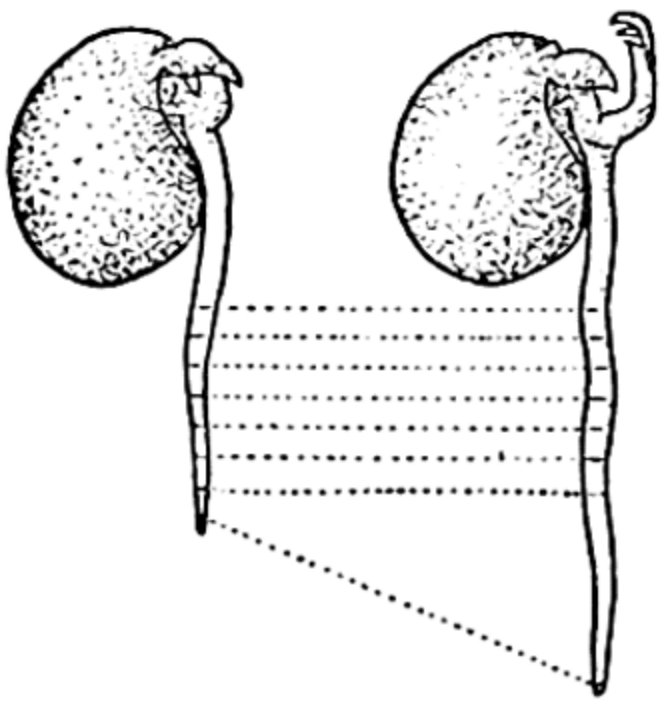


FIG. 65. Apical growth in a root

APICAL GROWTH OF ROOT AND SHOOT. To study these reactions in plants, we must first know something about their method of growth. When the axis of a plant elongates, growth is taking place only at the apex of each organ (cp. Figs. 65 and 66), as the following experiments will show.

Experiment 71. Take a broad-bean seedling with a straight root about 2 inches long. Dip a mounted needle (or long sewing-needle) into waterproof indian ink, and with the side of the needle (not its point) make marks on the root at intervals of about $\frac{1}{8}$ inch, starting at the root-tip and making the first mark on the root-cap itself.

Make an accurate sketch of the root and its marking, place the seedling in a gas-jar lined with moist blotting-paper, watch its growth, and sketch again. The root grows longer, but the only place where the distance between the marks increases is near the root-tip. The growth of the root is apical, elongation occurring in the last 2 or 3 mm. of the root, just behind the root-cap.

Experiment 72. Mark the plumule of the seedling in the same way, taking care that the marks are on the stem itself and not on

the leaves, and then observe the growth. Only some of the marks become more widely separated. Again growth is apical, but the elongating region is more spread out in the stem than in the root.

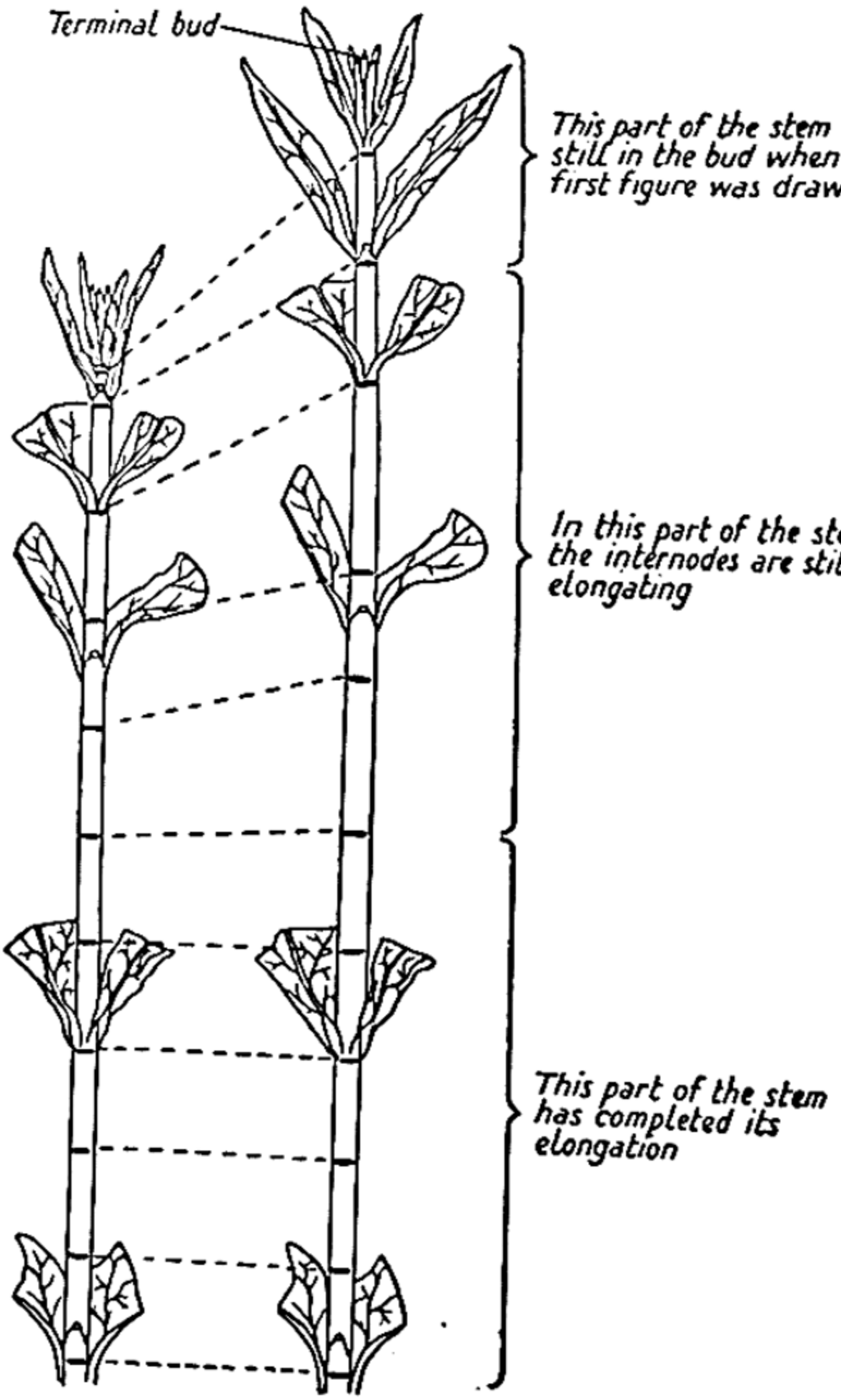


Fig. 66. Region of elongation in a typical stem

At the stem apex there is not only formation of the new axis, but this new axis almost immediately gives rise to the rudiments of leaves. These protect one another and the stem apex and form the terminal bud.

The most rapid growth in length occurs, not in the terminal bud itself, but in the internodes just below, where the axis elongates and so separates the young unfolding leaves.

Each internode in turn grows to its appointed length and then all further elongation ceases.

This apical elongation of the axis is very characteristic of plants, being found in many of the lower groups as well as in flowering plants. It usually continues all through life, so that new organs are always being added and the plant is growing taller. These organs all take up some quite definite position in space. Let us now ask how the direction of their growth is controlled.

TROPIC CURVATURES OF PLANT ORGANS.

Experiment 73. Take two seedlings with straight roots between 1 and 2 inches long. Mark the roots at equal intervals, as in experiment 71. Plant the seedlings in gas-jars as before, pointing the one root horizontally, the other vertically upwards. Sketch the roots as they appear at the beginning of the experiment, leave in a dark cupboard for a day, examine, and sketch again.

The root-tips now point vertically downwards. Careful comparison shows that they have curved in the growing region, the parts of the root which had finished elongating have not moved.

Experiment 74. Turn the seedlings round again, so that once more the one root-tip is horizontal, the other upright. They turn down again by another growth curvature.

GEOTROPISM. Obviously some force is directing the growth of the root. That force is gravity, to which influence all living organisms are exposed (cp. pp. 231 and 232). The root responds to gravity by growing and turning its tip downwards (cp. Fig. 67); we say that it is positively geotropic. It cannot respond, as an animal often does, by moving its whole body towards (or away from) the directing stimulus (cp. Fig. 64). The only parts capable of a visible response are the plastic new cells which are actually growing while the stimulus is effective.

The limited power of movement which plants possess should be carefully contrasted with those free and active movements of animals, which make their responses to external stimuli so much more rapid and obvious.

The response of the main stem to gravity is exactly opposite to that of the main root; it is negatively geotropic, growing vertically upwards away from the earth's centre, as is shown in the next experiment.

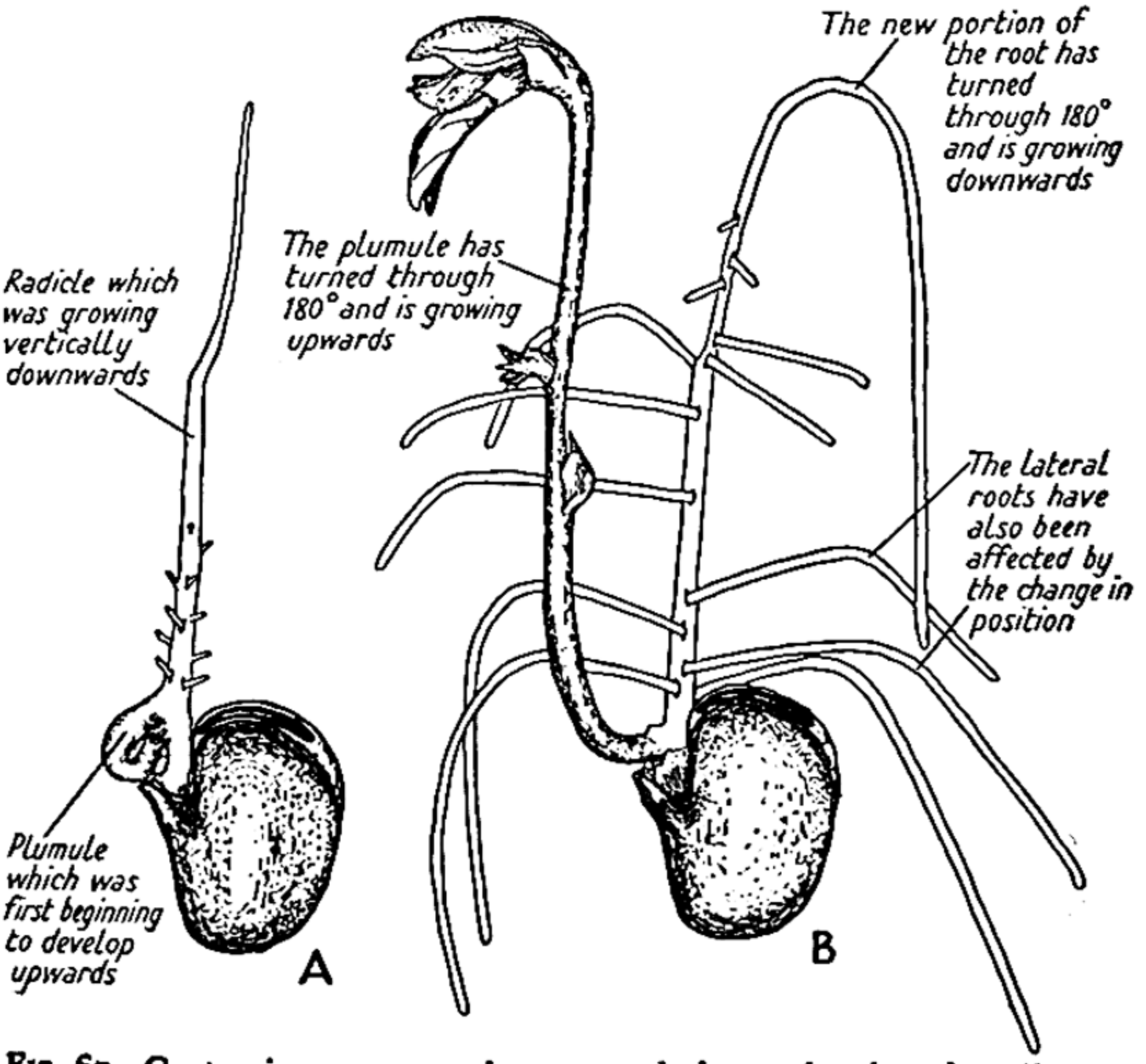


FIG. 67. Geotropic curvatures in root and shoot, showing the effect on its growth of turning a seedling plant upside down. **A.** Plant just inverted (×½). **B.** The same plant five days later (×½)

Experiment 75. To examine the response of the plumule to gravity we use pea or bean seedlings, grown in pots, and with plumules 2 to 3 inches long. Mark the stems in equal intervals with indian ink, tie muslin over one of the pots, and suspend one upside down in a dark cupboard. Place a second pot on its side in the dark.

The plumules grow, and in each case return to the vertical position (cp. Fig. 67).

'GEOTROPIC' CURVATURES DUE TO THE STIMULUS OF GRAVITY. We cannot eliminate the force of gravity, to see whether the plant's axis loses its sense of direction when not exposed to that influence. But experiments with a klinostat help us to realize that gravity *is* the stimulus which calls forth geotropic response. By this instrument we can keep a plant continually revolving in space, so that the position of its axis with regard to gravity is continually changing (cp. Fig. 68).

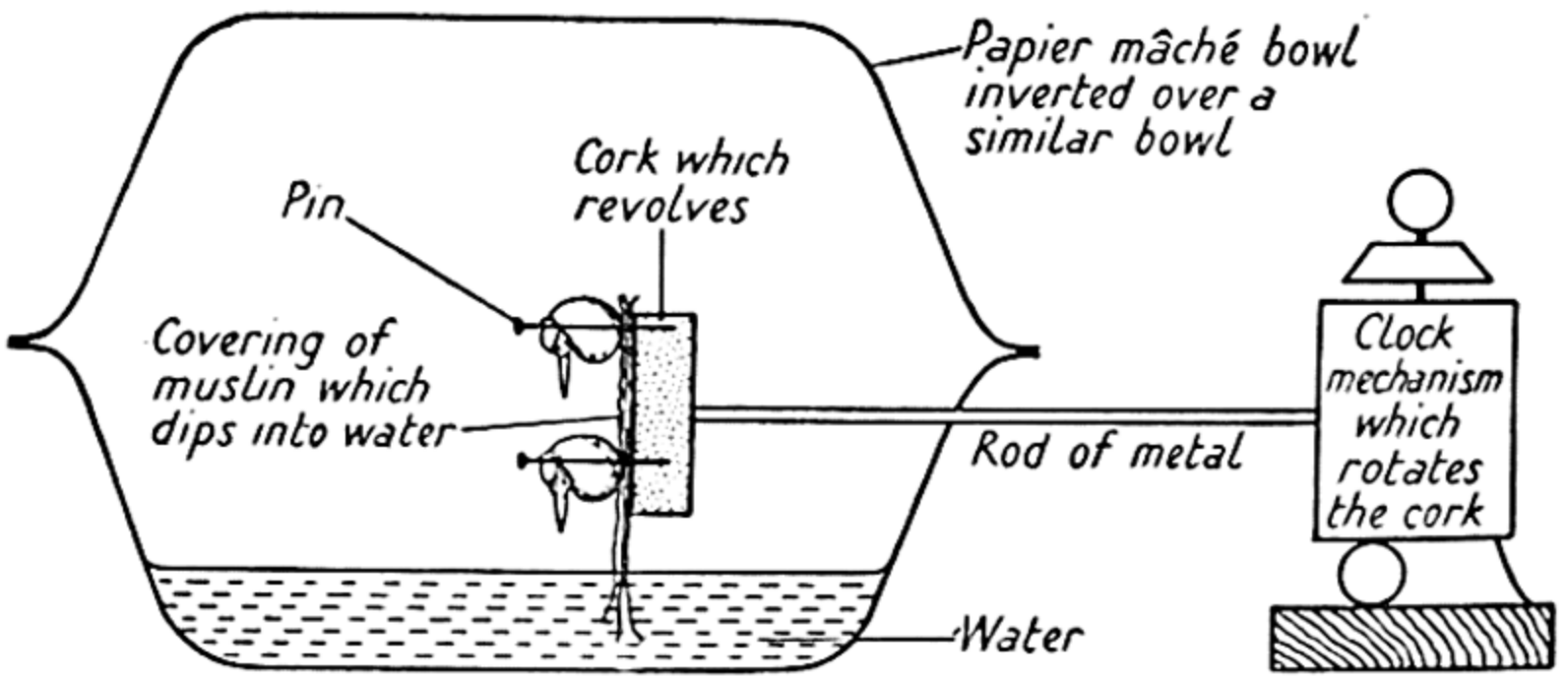


FIG. 68. Diagram of the klinostat apparatus described in the text

Experiment 76. A clock mechanism is made to revolve a metal rod to which a disk of cork is attached. The cork is covered with muslin, and some small seedlings (pea seedlings are suitable) with short, straight axes are fixed to it by pins thrust through the cotyledons. We wind up the clock, and the seedlings are revolved continuously in a vertical plane.

The seedlings must be kept both moist and dark; an excellent moist chamber can be made with two papier-mâché bowls, one being inverted and used as a cover to the other. A hole in the side of the lower bowl admits the revolving rod to which the cork is fixed. Water in the bottom of the bowl keeps the plants moist. As a control, set up a similar apparatus—cork and seedlings, bowls, &c.—but the cork is not revolved.

We find after about 24 hours that the seedlings in the control apparatus have grown, and their radicles now turn downwards, their plumules upwards (cp. Fig. 69 B). The revolving seedlings, on the other hand, have grown on in the position in which they were placed. They show no outward response to gravity (cp. Fig. 69 A).

In this manner we can show that geotropic curvatures represent the responses of the plant to the stimulus of gravity.

THE DIRECTIVE INFLUENCE OF LIGHT. HELIOTROPISM. Light as well as gravity exerts a directive influence on plant growth. We all know how room plants will turn their leaves towards the window. Let us examine these responses to light more closely.

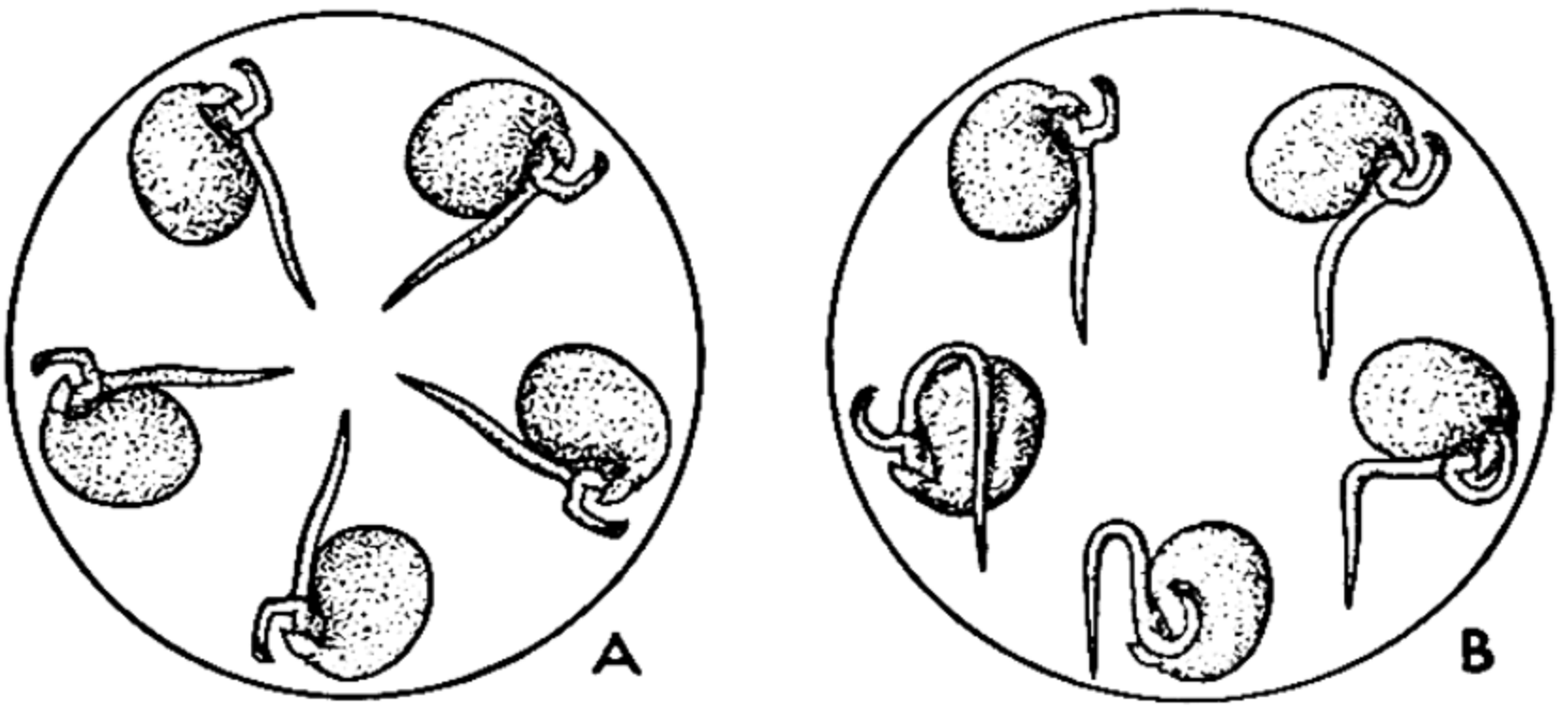


FIG. 69. THE RESULT OF A KLINOSTAT EXPERIMENT. **A.** Seedlings revolved. Roots and shoots have grown on in the direction in which they were placed. **B.** Seedlings not revolved. Roots have grown downwards and shoots upwards

Experiment 77. Fit a wide glass bottle with a cork, and pin to the middle of the cork a seedling with a short straight radicle. A little water at the bottom of the bottle creates a saturated atmosphere in which the radicle is suspended. Cover the whole with a box, in one side of which is cut a long, narrow slit, and place the whole apparatus against a window, so that light will pass through the slit and fall on the root apex from one side.

The *root* grows and turns away from the incident light. The main root of a seedling is negatively heliotropic.

Experiment 78. For this experiment use pea seedlings with short, straight plumules, about 3 inches long. Water them, and cover each plant by a box with a long slit in one side. Place in a window as in experiment 77.

The shoot grows towards the light, eventually coming out through

the slit in the box. The new growth is not horizontal, but nearly mid-way between the horizontal and the vertical. It is the result of two forces acting at right angles, gravity acting vertically while light acts horizontally under these conditions.

The *main shoot* of a seedling is positively heliotropic (cp. Fig. 70).

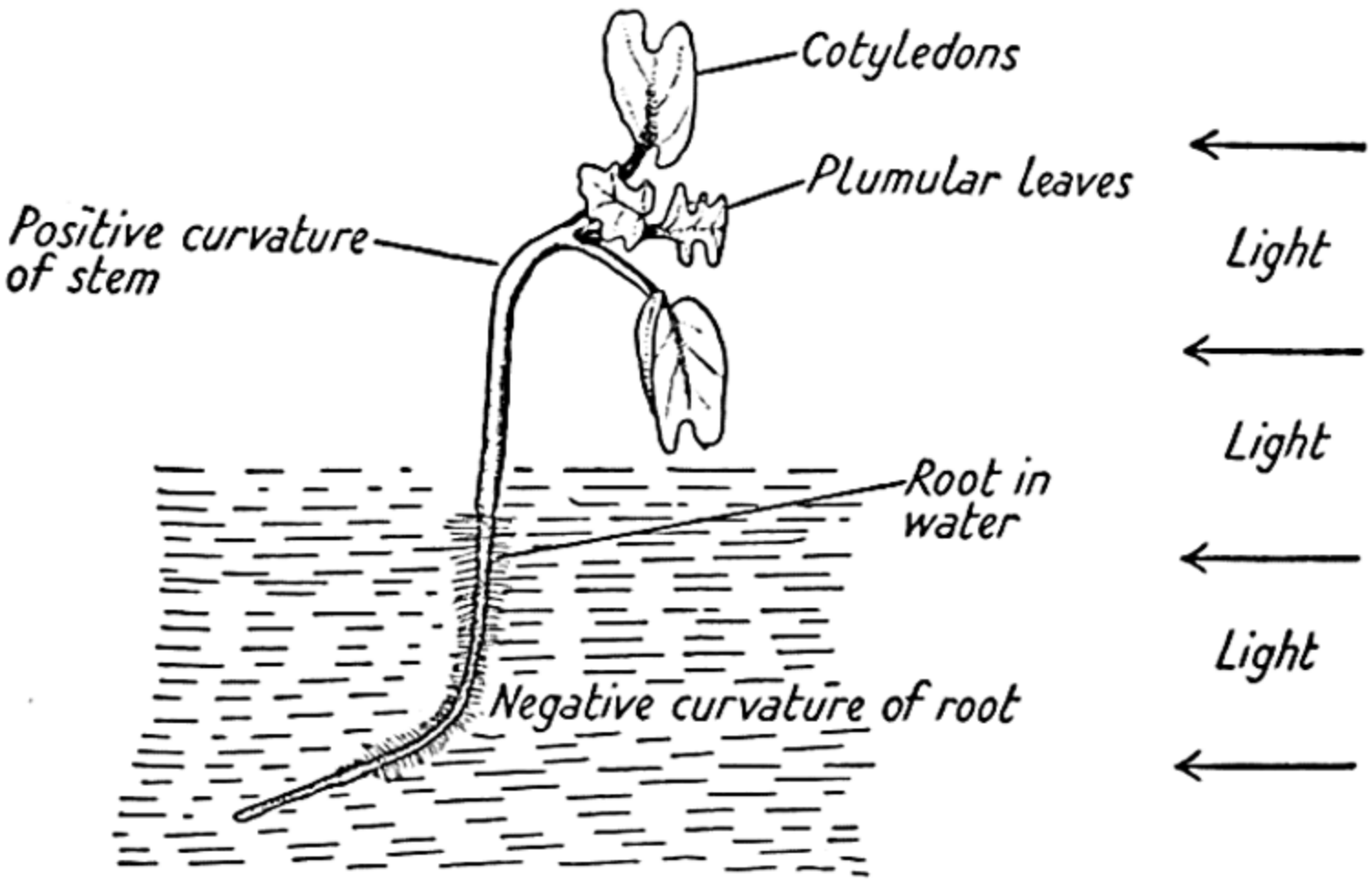


FIG. 70. Reaction of a cress seedling to light. (After Bower)

Experiment 79. Take two young plants of garden nasturtium (Tropaeolum); place one out of doors, cover the other with a box so that it is lighted from one side, and leave.

In the one plant the lamina of each leaf is now horizontal, in the other they are all vertical. In every case the leaf is set so that its lamina is at right angles to (i.e. across) the rays of light.

Leaves are sensitive to light. In temperate regions they usually set themselves to catch all they can—they are *diaphototropic*. This reaction is most marked in young leaves, and may quite disappear in old ones.

Experiment 80. Take two plants of garden nasturtium and place them in a well-lighted window. The one remains still, the other is placed on the cork disk of the klinostat (cp. Fig. 68), which is revolved in a *horizontal* plane. After a time all the leaves of the first plant face

the window; on the other plant, whose position to the light has been constantly altering, the leaves face in every possible direction.

We see that the position of the leaves is determined almost entirely by their reaction to light.

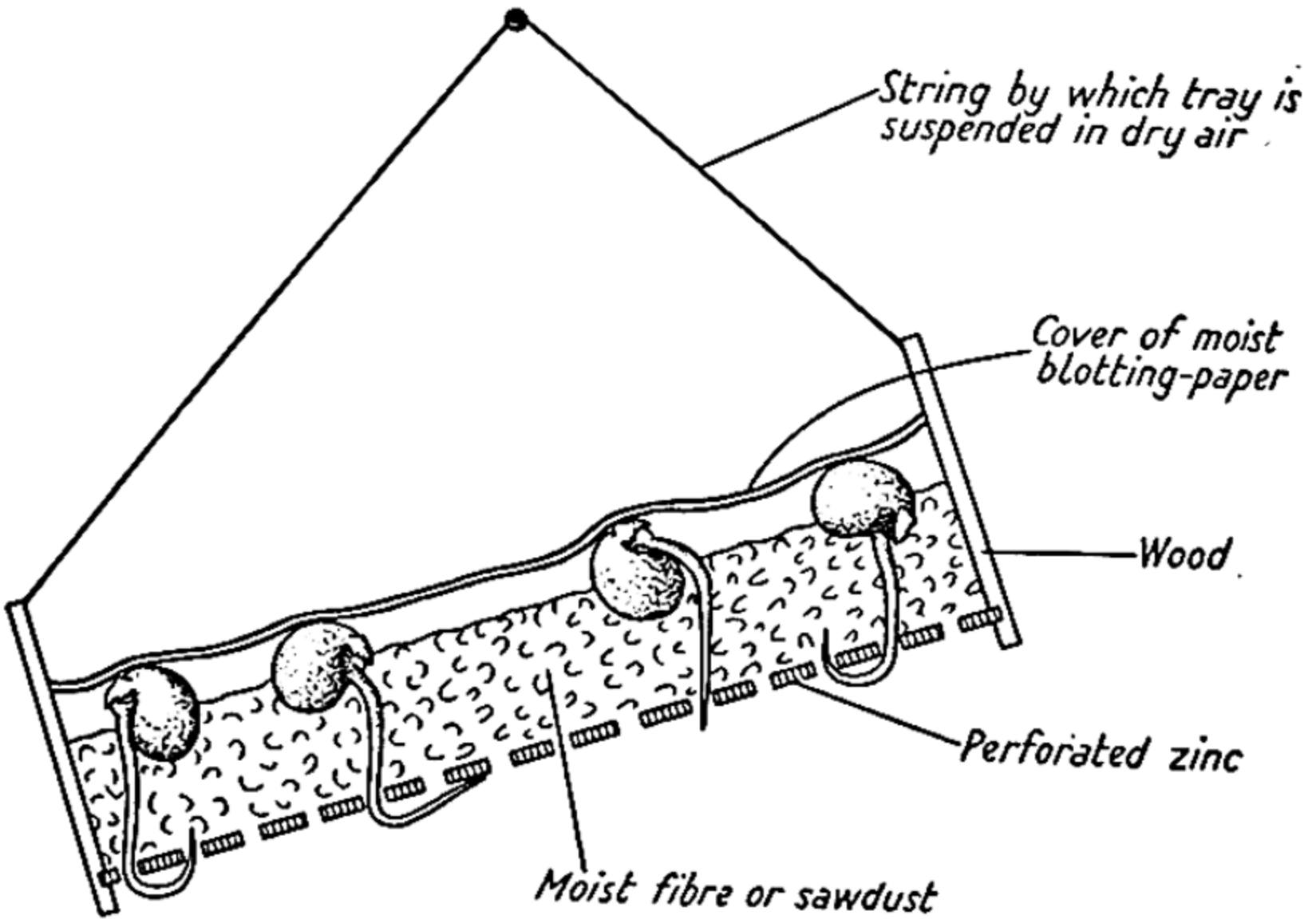


FIG. 71. Reaction of roots to moisture

THE DIRECTIVE INFLUENCE OF WATER. HYDROTROPISM. One more influence which directs the growth of plants remains to be discussed. This is the effect of moisture on roots.

Experiment 81. Make a deep tray of perforated zinc, cover the bottom with fine damp sawdust, and plant in it a number of small seeds. Cover the whole with damp blotting-paper and suspend the tray at an angle of about 45 degrees (cp. Fig. 71).

The seeds germinate and their roots grow vertically downwards under the influence of gravity. Some penetrate the holes in the zinc and their tips become exposed to dry air. They curve back towards the moisture, many pushing their way through another hole and entering the tray again. Sometimes a root may thread itself in and out of the holes several times.

Roots are sensitive to moisture, being positively hydrotropic (cp. Fig. 71). This response is obviously very valuable to the root, causing it to grow towards regions of greater moisture.

PLANT GROWTH DIRECTED BY EXTERNAL STIMULI—A SUMMARY. In both young seedlings and mature plants we have discovered that the position of the various organs is largely determined by their reaction to external stimuli. Gravity, light, and moisture all influence the growth of the root, which is positively geotropic, negatively heliotropic, and positively hydrotropic. The growth of the plumule is directed by light and gravity; it is positively heliotropic and negatively geotropic. The position taken up by the leaves depends chiefly on their reaction to light.

The lateral roots and shoots are also influenced by the same external forces (cp. Fig. 67 B), but their position is determined to a great extent by internal stimuli arising within the plant itself. The result is that they grow at a definite angle to the main stem (or root), this angle being very different in different plants. Compare, for example, a Lombardy poplar with a chestnut tree.

The plant is an organism, an individual, and, as in every other living organism, its acts are unified, the whole controlling the movements and other activities of its separate parts and organs.

Experiment 82. Suspend some broad-bean seedlings in separate gas-jars, each fixed by a long pin to a cork which closes the mouth of the jar. This arrangement allows the root system to develop freely. There is a little water at the bottom of the jar. When some of the lateral roots are from 2 to 5 inches long, cut off the end of the main root from half the seedlings. Notice the result carefully, sketching the mutilated roots every two or three days. In many cases a lateral root changes its direction of growth and turns vertically downwards, thus replacing the main root. Its response to gravity has been changed by some influence arising in another part of the plant.

MOVEMENT IN PLANTS AND ANIMALS. Movement is one of the great characteristics of living protoplasm. We now know that the popular idea that animals can move, but plants cannot,

is only partially true. Plants cannot, as a rule, move from place to place (movements of locomotion) as animals can, though even to this rule there are many exceptions. If you have ever seen a cinematograph film of a growing plant, in which, condensed into a few moments, you see events which represent months of active growth, you will realize as never before that all plant growth causes movement. As the tree grows its branches climb ever higher, its roots penetrate ever deeper into the soil. There are also these tropisms—turning movements which bring the various plant organs into the most advantageous position for the particular functions they have to perform.

Contrast between plant and animal movement. It is obvious that most plant movements are very slow, those of animals much more rapid. In plants a stimulus must act for some time before any response is visible; animals react almost instantaneously (cp. exercise, p. 223). It has been found, for example, that plants do not usually respond to the stimulus of gravity unless they are exposed to it (e.g. are laid horizontally) for at least twenty minutes, and some hours must often elapse before any measurable response can be detected. The contrast between this and the rapid responses of most animals is very marked.

This difference does not seem to rest on a fundamental difference between plant and animal protoplasm, for occasionally (cp. Fig. 44 B) plants can move quite rapidly. It depends largely on the animal's greater freedom of movement, animal protoplasm not being limited and restricted in its movements by inert, lifeless cell-walls, such as hem in the protoplasm of plant cells. Further, most animals have, in sense organs and nervous systems, a much more elaborate mechanism for receiving and transmitting stimuli. They also have cells specialized to carry out quick responses, in particular their muscle cells, which have great power of contraction. Hence each stimulus is rapidly received and efficiently transmitted to a definite effector organ. No such arrangements have been detected in plants, except that, in a few instances, plants seem to possess definite sense organs for the reception of stimuli, comparable to the sense organs of animals.

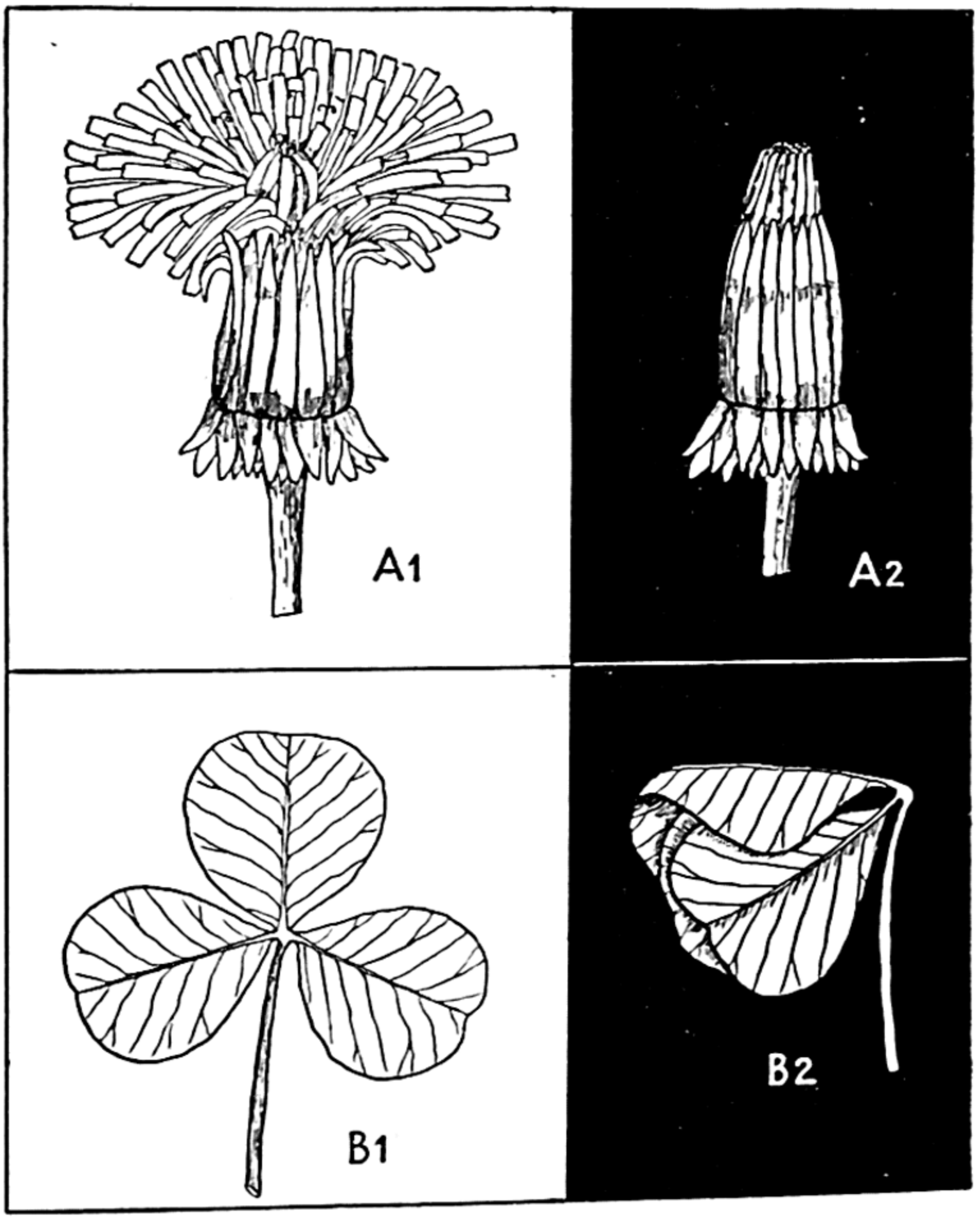


FIG. 72. SLEEP MOVEMENTS. **A1.** Dandelion flower, 6 a.m.–5 p.m.; **A2,** 5 p.m.–6 a.m. **B1.** Clover leaf in the light; **B2,** in the dark

SENSE ORGANS OF PLANTS.

Gravity-perception organs. The best-known sense organ of the plant is the gravity-perception organ situated in the root-cap, an organ which was described and examined by the great Charles Darwin.

It consists, as we have seen (cp. p. 231), of a group of cells, called statocytes, which contain movable starch grains, statoliths (cp. Fig. 60). The *reception* of the stimulus, when the plant is displaced, is brought about, we imagine, by movements of the statoliths, their movements stimulating the protoplasm of the statocytes; this stimulus is transmitted to the growing cells of the root apex, *transmission* taking place through the general protoplasm. (In this connexion we may recall the fact that fine strands of protoplasm penetrate the cell-walls of plants, so establishing a living connexion between the contents of adjacent cells.) The *response* to the stimulus is carried out by the new cells which are in process of formation. The whole process is quite comparable to the reflex action of an animal (cp. p. 222).

Experiment 83. Repeat experiment 73, carefully removing the root-cap with a very sharp razor. Measure the length of the root carefully, and place it vertically upwards, as before. The root grows, but does not curve until a new root-cap has been formed. It has lost, for the time, its sensitiveness to gravity (cp. Fig. 60 B).

Exercise. Examine a thin longitudinal section of a root apex which has been mounted in glycerine and iodine, and notice the statoliths.

Perception of light. Another localized sense organ occurs in the first leaf (coleoptile) of grasses (cp. Fig. 110 A); it has a solid tip which acts as a light-receiving organ. If the top 2 mm. of this leaf is removed there is no response to a one-sided light-stimulus; if this tip is covered by an opaque silver-paper cap, the response is much reduced. These facts can easily be demonstrated by simple experiments.

Contrast between plant and animal movement (continued). Hence even in this matter of the possession of definite sense organs there is no absolute distinction between plants and animals.

In as highly organized an animal as an earthworm no organs for orientation or for seeing have been detected. All the higher plants apparently possess at least one localized sense organ in the root-cap.

RAPID MOVEMENTS EXECUTED BY CERTAIN PLANTS. *Sleep movements.* Have you noticed that clover leaves change their position at night? The leaf consists of three leaflets, which spread out horizontally by day; at night the two side leaflets fold together with their upper surfaces in contact; the third leaflet then swings over these two and is folded along its mid-rib, so that it covers the others (cp. Fig. 72 B). What stimulus causes this movement?

Experiment 84. Invert a wooden box over a clover plant growing in the open, taking care that all light is excluded. Determine how long the leaflets take to assume the 'sleep' position.

Sleep movements are shown by many compound leaves; e.g. those of wood-sorrel and the 'sensitive plant'. The exact meaning of these movements is not known.

Opening and closing movements in flowers. Many flowers open by day and close at night, e.g. buttercups, dandelions. In these the change from light to darkness seems to be the chief stimulus. In others changes in temperature cause the movement. Every one knows how tulips open in a warm room and close in a cold one. In many cases flower movements are probably caused by a combination of these two stimuli; this seems to be true of the opening and closing of crocus flowers. There are other flowers which open only at dusk—e.g. evening primrose, tobacco flowers, night-scented stock.

Many plants carry out movements of this nature. The student should try to find others for himself.

Movements due to contact stimulus. It is in certain movements due to contact that plant responses most nearly resemble those of animals. Sundew hairs (cp. Fig. 44 B) bend down quite quickly over any insect which touches them, and the stimulus is communicated to hairs not actually touched, so that they also bend.

Very rapid are the movements of the sensitive plant, which may be induced by contact, and also by change from light to darkness (sleep movements). This plant has compound

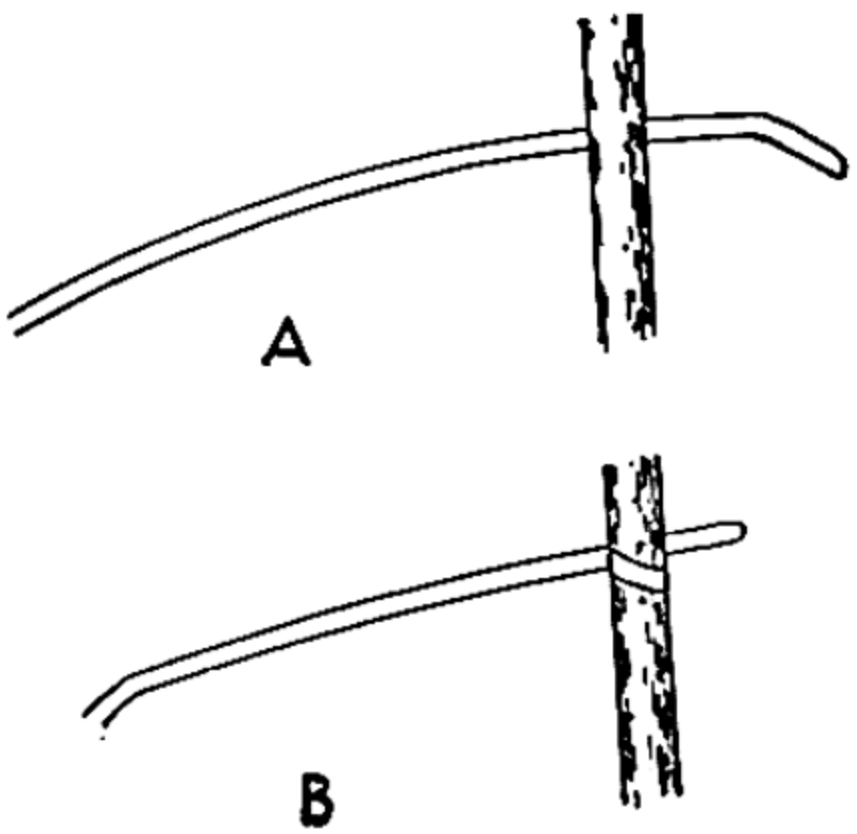


FIG. 73. Stages in the twining of white bryony. **A.** Tendril stimulated by contact. **B.** Tendril beginning to react to the stimulus. **C.** The reaction completed. The whole tendril has responded

leaves, each consisting of many leaflets; if one of these is pinched or burned, all the leaflets fold together in pairs, the whole leaf moves downwards; the effect of the contact is rapidly communicated to adjacent leaves, which droop in turn. In a few minutes the whole plant has dropped its leaves into the 'sleep position'.

The responses in both these cases are almost as quick as those of animals.

Climbing plants. Many climbing plants respond to contact, growth becoming more rapid on the side opposite to that touched; as the result of this they twine round some support (cp. Figs. 49, 73). This reaction is best seen in *tendrils*, special climbing organs which many plants possess, and which usually represent modified leaves, leaflets, or branches (cp. Figs. 121 and 122).

Exercise. Examine the tendrils of sweet pea, vetch, bryony, &c., and try to determine their morphological nature, i.e. do they represent leaflets, whole leaves, branches, &c.?

Experiment 85. Gently stroke the under surface of a young white bryony tendril for about a minute, and notice that curvature follows almost immediately. The tendril curves from both ends, and hence both fixes the plant to the support and drags it up towards the light. Sketch one of these tendrils, and compare its coiling with that of a rope which is twisted from both ends.

PLANT MOVEMENT. A SUMMARY. Once more, in this study of movement, we find that certain fundamental activities are common to all protoplasm. Sitting in a room with a dog and a geranium as the other living occupants, we notice the dog's respiration, but not the geranium's; we notice the dog's feeding, but not the plant's; we notice his movements, his responses to varying stimuli; we are not conscious of movement in the plant.

Yet all these things are common to the three organisms. They are fundamental characteristics of all living protoplasm.

QUESTIONS ON CHAPTER XX

1. 'Irritability' is one of the properties common to all living things. Explain the meaning of this term. How is the truth of this sentence shown in the behaviour of (*a*) a mouse, (*b*) Amoeba, (*c*) a germinating seed, (*d*) a sweet-pea plant? (L.M.)

2. How do stems and roots respond to the stimulus of (1) light, (2) gravity? Describe experiments you have performed in proof of your statements. (L.G.S.)

3. What is meant by geotropism? Write a full description of any three experiments you have performed which throw light on the nature of geotropic response in roots.

4. Describe simple experiments to show how the growth of a root is affected by gravity, light, and by moisture. (J.M.B.)

5. Describe any two experiments you would perform to show clearly the effect of light on the direction of growth of the plumule. State briefly what are the other effects of light on plants.

6. What do you understand by a tropism? Carefully compare any one plant tropism with any one reflex action in a mammal. (L.G.S.)

7. What do you understand by contact stimulus? Describe any one reaction to a contact stimulus in a vertebrate animal, and any one reaction to contact by a plant. Briefly compare the two.

8. Write a short essay on sensitivity in plants.

9. Write a short essay on movement in plants, and briefly compare plant and animal movement.

10. Write a short essay on the response to stimuli among plants. (L.G.S.)

11. Give an account of experiments you have made relating to the reaction of shoot and root respectively to gravity and light. (C.W.B.)

12. How would you set up an experiment to demonstrate that roots are positively hydrotropic (i.e. turn towards moisture)? What precautions would you take to make sure that the movements observed are not due to some other stimulus? (O. & C.)

13. Describe three simple experiments to show the response of different parts of the shoot system of plants to the stimulus of light. What advantages do plants obtain from their irritability to this stimulus? (L.G.S.)

14. Give a concise account of any experiments you would make to demonstrate the responses of the various parts of a plant to the stimulus of *either* (*a*) light, *or* (*b*) gravity. (C.W.B.)

15. Explain concisely what you understand by 'irritability'. Give

illustrations from among the organisms you have studied, both plant and animal. (L.G.S.)

16. 'Sensitivity' or 'irritability' is one of the characteristics of all living things. Explain the meaning of these terms. How is 'sensitivity' or 'irritability' demonstrated in the behaviour of (*a*) a seedling, and (*b*) a frog? [Details of structure are not required.] (J.M.B.)

17. Give a brief account, illustrated by examples, of the responses made (*a*) by plants, (*b*) by animals, to various external stimuli. (L.G.S.)

18. What is meant by 'geotropism'? How far is geotropism of value to plants? Explain how you could demonstrate geotropism in a plant organ, and make drawings to illustrate your account. (C.L.)

19. To what stimuli do plants react? Describe *three* experiments, each of which would demonstrate the effect of *one* of these stimuli. (Ox. & C.)

PART V

FOOD AS A SOURCE OF ENERGY

CHAPTER XXI

RESPIRATION

USES OF FOOD. Having discovered how plants and animals obtain food, we must now ask why food is so necessary. Living implies activity; to be alive is to be 'up and doing'. Living also implies growth; all living things grow at some stage of their existence. Hence food is needed for two main purposes:

(1) To supply the *energy* required for all living activities.

(2) To supply the *material* from which new protoplasm can be made, both to repair waste and to build the new cells necessary for growth and reproduction.

FOOD AND ENERGY. In some ways active protoplasm can be usefully compared with a machine. A steam-engine or a motor-car requires fuel (coal, petrol) to provide the energy which makes it 'go'. The fuel is burned (oxidized) somewhere in the machine and its potential energy is set free. In the case of the steam-engine and the motor-car this energy is used to cause movement; there are other machines in which the oxidation leads to the production of electricity or is used to supply heat and light. This oxidation of fuel is a chemical process (combustion) and you probably know something about it already. It always leads to the formation of waste substances which escape at the exhaust, &c., no matter being really destroyed during combustion.

RESPIRATION. Now protoplasm supplies itself with energy by a process which, in certain ways, is similar to combustion. Living organisms consume food as an engine consumes fuel, oxidizing it to obtain energy. This oxidation, like combustion, leads to the formation of waste products, carbon dioxide, water, &c., which are useless or even injurious to the protoplasm, and must be allowed to escape.

Respiration is the name of this process, and it is carried out by every living cell. It is a biochemical process allied to combustion, though there are some forms of respiration, called anaerobic, which do not depend upon the oxygen of the air. We turn now to study this process experimentally.

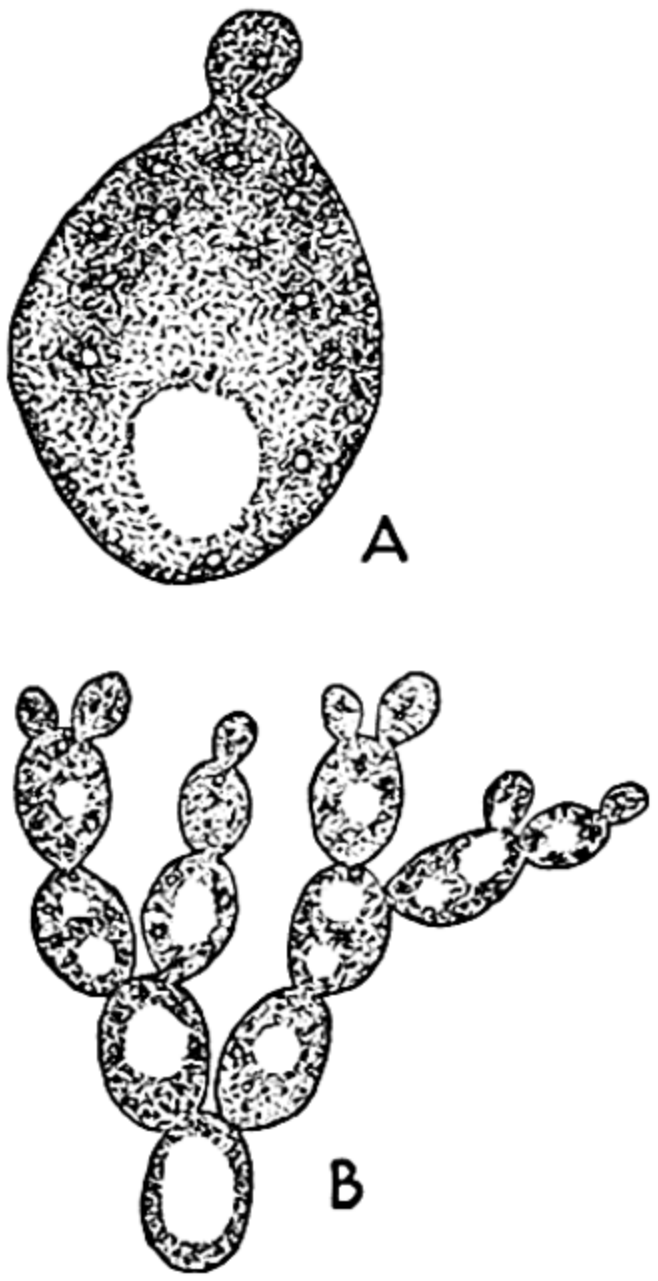


FIG. 74. YEAST.
A. One yeast plant (× 2,500).
B. Budding plants

ANAEROBIC RESPIRATION. Obtain a little baker's yeast. The putty-like mass consists of innumerable minute, colourless oval cells, each cell a whole plant, and yet so small that very little structure is visible, even under the microscope. When the yeast comes from the baker these cells are inactive.

Experiment 86. Place a fragment of yeast in a flask which contains some sugar dissolved in water. Close the flask with a rubber stopper carrying a delivery tube. Let the free end of the tube dip into clear lime-water. Place the apparatus in a warm place. Very soon bubbles of gas begin to escape into the lime-water, which rapidly becomes cloudy. *Carbon dioxide is escaping* from the flask. How is this being formed and what is the meaning of its formation?

Experiment 87. Obtain two thermos flasks and wash them very thoroughly with boiling water. Put into one some yeast in a sugar solution, into the other yeast in distilled water. Plug both flasks with cotton-wool, having inserted a thermometer in each with the bulb in the solution.

We find a *rapid rise of temperature* in the first flask, but no such rise in the second.

These experiments show that some activity is going on in the preparations of yeast and sugar which leads to the libera- tion of heat and the production of carbon dioxide. At the same time the yeast is growing, as is made clear by the next exercise.

Exercise. Remove some of the liquid used in the previous experiments, mount a little on a slide, and examine under the microscope. It contains numerous minute yeast cells and many of these are actively 'budding', i.e. growing and giving rise to little outgrowths (cp. Fig. 74) which soon become full-sized new cells.

We have provided the yeast with food (sugar); not being green, it cannot manufacture this substance for itself (cp. p. 62). The yeast protoplasm decomposes this sugar with the help of enzymes (cp. p. 126), and so obtains the energy which it needs for growth and all its vital activities. One product of this decomposition is a substance, carbon dioxide, which, being of no further use to the yeast cells, escapes and passes into the air; the other waste product is alcohol, which likewise escapes from the yeast but remains dissolved in the nutrient solution. We may represent the process going on in these cells by the following equation:

$$\underset{\text{glucose}}{C_6H_{12}O_6} = \underset{\text{ethyl alcohol}}{2C_2H_5OH} + \underset{\text{carbon dioxide}}{2CO_2},$$

though this equation represents it too simply. The decomposition of the sugar is doubtless more gradual than this equation suggests, various intermediate products being formed (cp. p. 64).

Most of the energy released appears as heat; this heat caused the rise of temperature observed in experiment 87.

FERMENTATION A FORM OF RESPIRATION. The decomposition of sugar solutions by yeast (called *fermentation* [Latin, *fervere* = to boil] because of the gas produced) is a process which has been known by its effect for a very long time. It causes the leavening of bread and the conversion of grape-juice into wine. It was PASTEUR who first showed that all such processes are due to the activity of some living organism (cp. p. 204).

Fermentation may be regarded as one form of respiration, for it is a chemical process by which certain living cells obtain energy. This type of respiration is called *anaerobic*, since the protoplasm can carry out the necessary decompositions without the participation of the air. Although most living things

use oxygen in their respiration, it is well to realize from the beginning that oxygen is not always essential. Anaerobic respiration is a form of respiration which takes place without it.

AEROBIC RESPIRATION. What is the nature of aerobic respiration, i.e. of the form of respiration which needs the oxygen of the air? The following experiments shed some light on this question.

Experiment 88. To show that oxygen is absorbed during aerobic respiration place some soaked pea seeds in the bottom of a large gas-jar. Wedge them in position by means of a disk of perforated zinc, and then invert the jar over a trough containing a solution of caustic potash. (N.B. The reason for using caustic potash instead of plain water will become clear later. Exp. 89.)

Place a second similar jar side by side with the first as a control. This second jar contains fragments of moist blotting-paper in place of the peas.

Leave the apparatus in a warm place for 48 hours.

We find that the solution has risen in the first jar, and this shows that some gas has disappeared from that jar. We therefore test its contents with a well-lighted splint, and find that the splint is immediately extinguished. There is *no oxygen* in it. These changes have not taken place in the control jar. They are due to the peas, which are absorbing oxygen for respiration.

Experiment 89. To show that living organisms give off carbon dioxide during respiration we set up the apparatus shown in Fig. 75. At the beginning of each experiment there are two jars containing clear lime-water, while the living creatures under observation are in the central jar.

When all joints are air-tight we open the tap of the pump, and cause a current of air to pass through the apparatus. The entering air is deprived of carbon dioxide by the caustic potash, and the lime-water in the first jar remains clear. The air passes on, and bubbles through the second jar. Here the lime-water becomes distinctly cloudy. *Carbon dioxide is given off as a waste product during respiration.*

The apparatus just described may be used for many interesting experiments. Various living organisms may be placed, one after the other, in the central jar, e.g. earthworms, kept moist in damp moss; a live frog; soaked seeds; opening tree or flower

buds; crocus corms; plant roots, &c. If green plants are used this jar must be covered with a black cloth, to stop photo-synthesis. For each new experiment we fill the second bottle with fresh lime-water, and each creature in turn reveals its secret. It is giving off carbon dioxide.

Further, we may study the effect of external conditions, such as changing temperature, on the production of carbon dioxide.

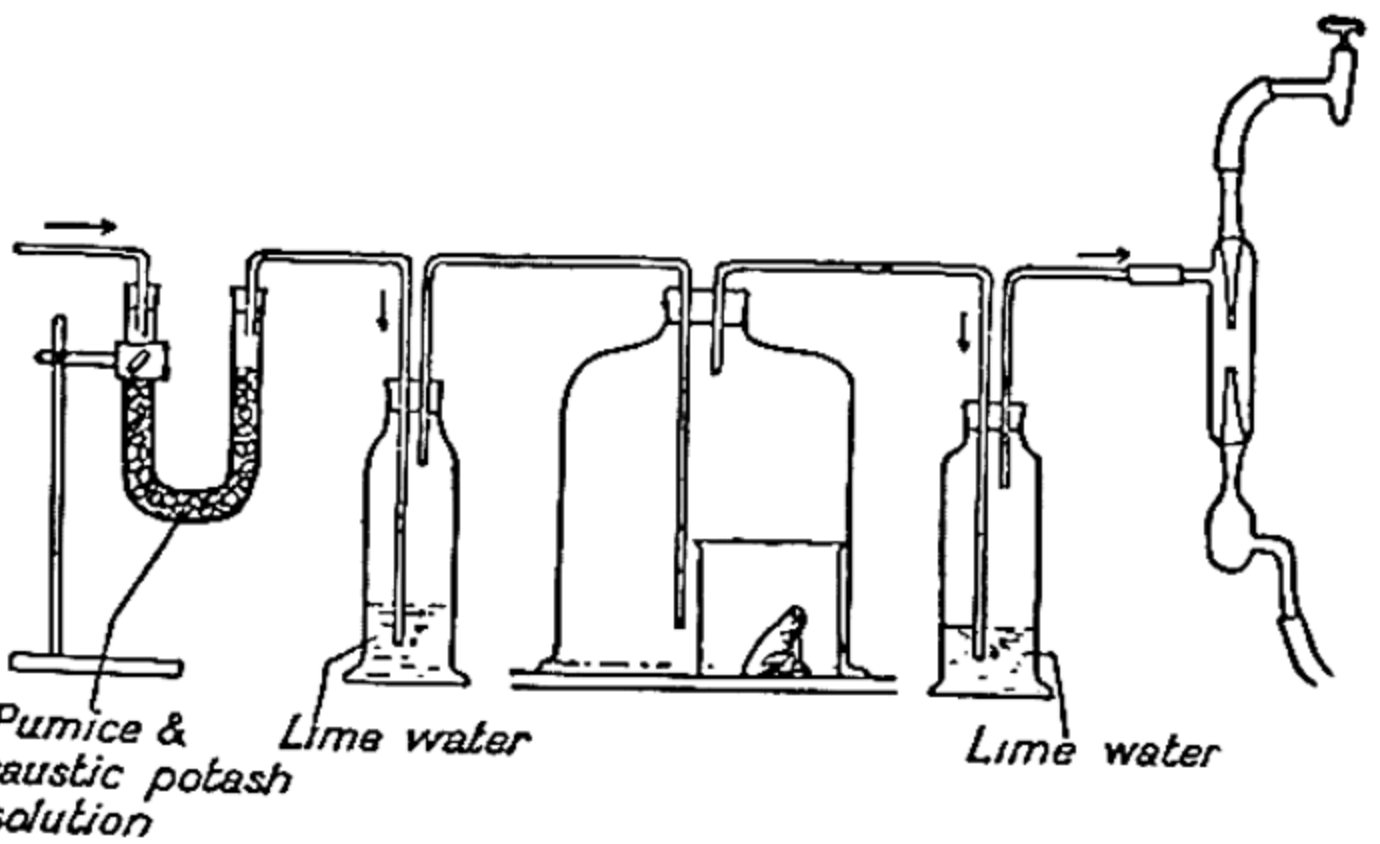


FIG. 75. Apparatus for demonstrating respiration

We put seeds, for example, in the central jar and surround this jar with ice. Turn on the water and let the apparatus run for 10 minutes.

Then surround the seeds with water at 30° C. When they have had a few minutes to adjust themselves to the change of temperature, put clean lime-water in the second jar and run the apparatus again for 10 minutes.

The lime-water now becomes much cloudier than it did before. The output of carbon dioxide is increased as the external temperature rises from 0° to 30° C. If, on the other hand, the temperature becomes too high (over 40° C.) the output falls off rapidly and soon stops altogether. Respiration, like all other vital activities, can only take place between certain well-defined limits of temperature (cp. 354).

Experiment 90. Blow some of your own breath (expired air) through a glass tube into lime-water. The lime-water quickly becomes cloudy. Without a control experiment this proves nothing, for ordinary air contains a trace of carbon dioxide (0·04 per cent.), but it strongly suggests that human expired air is richer in carbon dioxide. To prove this set up the apparatus shown in Fig. 76. Place equal volumes of lime-water in the two flasks and then breathe slowly in and out, through the mouthpiece *A*. The air you draw in passes through flask 2, that which you breathe out escapes through flask 1. The lime-water in this flask is soon much milkier than that in 2. Thus, with a proper control we demonstrate that our breath contains more carbon dioxide than does ordinary air.

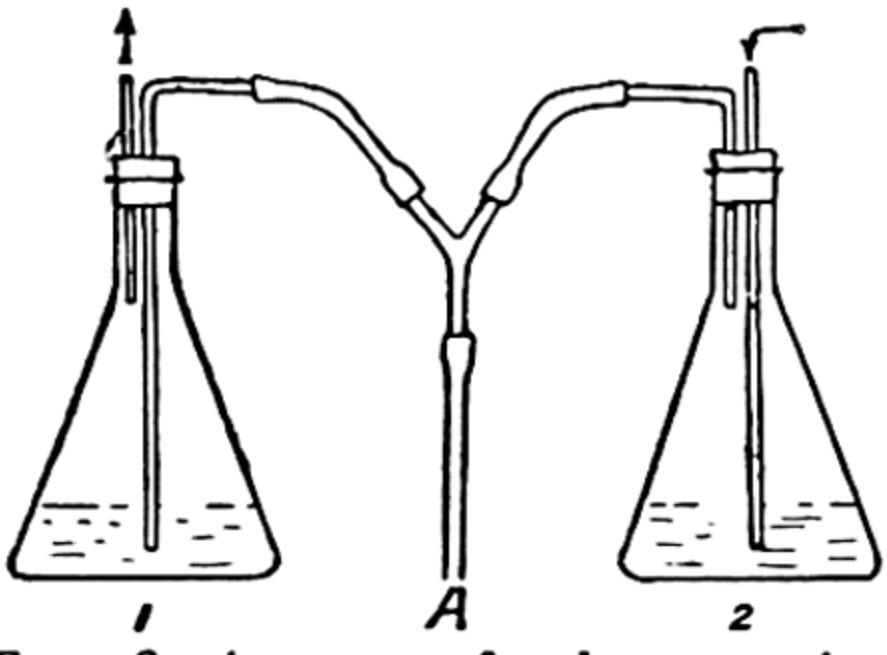


FIG. 76. Apparatus for demonstrating that human beings give off carbon dioxide in the breath

Accurate chemical analysis has shown that we both remove oxygen from the air and increase the amount of carbon dioxide it contains. Human being or pea seed—in this respect we are all 'one flesh'; during respiration we use up oxygen and give off waste carbon dioxide, as is shown by the following table:

	Human inspired air, i.e. ordinary atmosphere	*Expired air*
Oxygen . .	20·93 per cent.	16·4 per cent.
Carbon dioxide .	0·03 „	4·1 „
Nitrogen . .	79·00 „	79·5 „
Water vapour .	a trace	0·6 „

The air which we breathe out is also warmer and moister than the air we breathed in, and it contains various organic impurities.

Our need for oxygen has been well illustrated in the many attempts to climb Mount Everest. The chief difficulty is not lack of food, lowness of temperature, impossible and precipitous rocks, or anything of that kind, but just lack of oxygen.

Airmen who want to fly at an altitude of 16,000 feet or above must carry a supply of oxygen, and it is suggested that a flyer's judgement is probably improved by oxygen even at much lower altitudes. The flyer can carry oxygen cylinders with him; the energy to raise this weight comes from the petrol. The climber must support them himself if he wants an added supply, and that when his whole physical and moral fibre is weakened by lack of oxygen. It remains to be seen whether man can adapt himself to these extreme conditions.

'As compared with other mammals', says Professor J. B. S. Haldane, 'man is very efficient at adaptation. Cats generally die at 14,000 feet, while cows die at 15,000 feet and give no milk above 13,000 feet, even in the tropics. There is, however, a limit even to human adaptability.'

ENERGY SET FREE DURING RESPIRATION.

Experiment 91. To demonstrate a release of energy in the form of heat during aerobic respiration we repeat experiment 87, packing the first flask with soaked pea seeds which have been well washed in a weak solution of potassium permanganate (a disinfectant). The second flask contains seeds which have been killed by boiling in potassium permanganate. A thermometer is inserted among each set of peas, the flasks are plugged with cotton-wool, and the temperatures are read at frequent intervals. (N.B. The object of the disinfectant is to hinder germ action—germs being living things, they also respire and produce heat.)

In an experiment of this sort done very accurately, the temperature of the living peas, which started at 18° C., rose to 38° C. by the end of the fifth day. There was no rise in the control flask. This investigator (PIERCE, 1912) calculated that 75 gm. of dry sterilized pea seeds had liberated 2,593 calories of heat in 7 days.

Although it is difficult to be quite certain that all this heat is produced by the peas (in spite of precautions, some of it may

be set free by anaerobic bacteria), yet the experiment illustrates the fact that heat energy is set free during respiration. We know how the presence of a number of human beings can raise the temperature of a cold room. By suitable apparatus (cp.

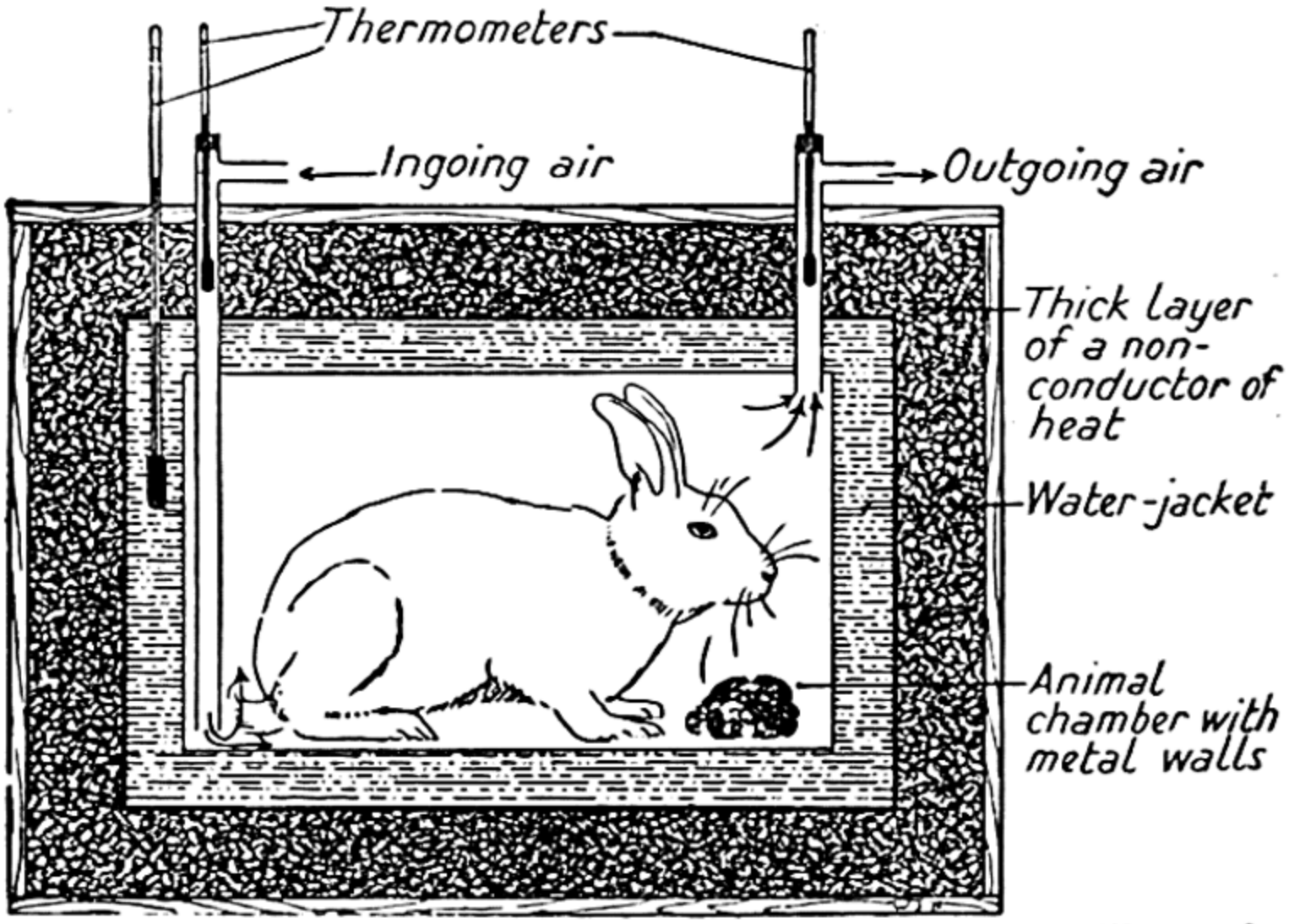


FIG. 77. An animal calorimeter for measuring the heat liberated during respiration. We know the volume of the water and read off its rise of temperature. From this the heat liberated can be calculated. (After Argyll Campbell)

Fig. 77) we can measure the heat liberated during the respiration of any living organism.

RESPIRATION ALSO CAUSES A LOSS OF WEIGHT; this must be so, since it involves a consumption of food. If food is withheld from an animal, or a plant is prevented (e.g. by being kept in the dark) from manufacturing food, this loss in weight soon becomes apparent. 'We are all very thin', said poor Scott, writing during his tragic Polar expedition, when they had little food and were losing heat at a great rate.

Experiment 92. To show that plants lose weight during respiration, take two sets, *A* and *B*, of soaked pea seeds. The sets are of equal weight. Dry set *A* at 100° C. and record the dry weight. Line a gas-jar with blotting-paper, place the seeds of set *B* between the

paper and the glass, keep them moist, and leave in the dark to grow. When the seedlings are well developed, dry them and obtain their dry weight. This is always *less than the dry weight of the ungerminated seeds.*

In one careful experiment the dry weight of 100 sunflower seeds was 7·3 gm.; of 100 ten-day-old seedlings 5·7 gm. This was a loss of approximately one-fifth (20 per cent.) of the original dry weight of the seeds.

The food was used to provide the energy for growth, for pushing the roots into the soil and carrying cotyledons, &c., up above the ground. Respiration always involves a consumption of food, and animals eat and plants assimilate very largely to renew the supplies they need for this purpose.

RESPIRATION. A SURVEY. Our experiments have illustrated the following facts about respiration:

1. It is a fundamental activity of all protoplasm, taking place in every living cell, whether of plant or animal.
2. Food is decomposed, generally by a process of chemical oxidation which sets energy free.
3. This energy is set free for the use of the protoplasm, each cell obtaining its own supplies.
4. In all aerobic respiration oxygen from the air is consumed.
5. Carbon dioxide and other waste products, e.g. water, are formed and given off to the surroundings.
6. The process goes on continuously, so long as the cell is alive.
7. Weight is lost as the result of respiration.

This process of respiration furnishes the driving power by which protoplasm keeps itself alive. All work involves the expenditure of energy, and without work (activity) there is no life. Respiration is the process by which this energy is obtained.

ALL ENERGY IS DERIVED FROM THE SUN. Respiration releases energy, but what is the ultimate source of this energy on which life depends? Its immediate source is, of course, the food that serves as fuel. But food is the product of green plant cells, and the sun's energy is essential for the first stage of its production.

From this point of view sugar is simply 'bottled sunlight'; all green plants store energy in the course of making food. Since in all processes of respiration, wherever they occur, energy is obtained by the oxidation of food, it is obvious that the energy so set free was originally derived from the sun.

Another fact to notice is that green plants have two sources of energy—they obtain some directly from the sun, and they release some from their food in the course of respiration. Animals, for all their major activities, can only use the latter source of supply.

COMPARISON OF ANAEROBIC AND AEROBIC RESPIRATION. All respiration is a decomposition of food accompanied by a release of energy. The chief difference between anaerobic and aerobic respiration is that, in the latter, oxygen is absorbed from the atmosphere and used in the chemical processes that take place. This oxygen enables the protoplasm to bring about a more complete decomposition of the fuel than is possible without it. When yeast breaks down sugar, for example, alcohol is one of the waste products formed. Now alcohol (e.g. methylated spirit) still contains a considerable amount of energy that could be transformed to heat, as any one will realize who has used a methylated-spirit stove.

In aerobic respiration sugar is oxidized completely to carbon dioxide and water:

$$C_6H_{12}O_6+6O_2 = 6H_2O+6CO_2,$$

instead of

$$C_6H_{12}O_6 = 2C_2H_5OH+2CO_2;$$

which, as we have seen, represents alcoholic fermentation.

This oxidizing of a given weight of glucose to carbon dioxide and water furnishes twelve times as much energy as is obtained by decomposing it into carbon dioxide and alcohol. It is, therefore, not surprising that respiration is usually aerobic; indeed animals, as a rule, die very quickly if deprived of oxygen. Yet there are a few internal parasites, e.g. threadworms, tapeworms, which seem to exist without oxygen; and even in the higher animals the muscle cells, which bring about all the animal's movements, begin the decomposition of their fuel anaerobically; oxygen is only used in the latter stages of this process.

Plant cells are not killed so quickly by the absence of oxygen, as the following experiment shows.

Experiment 93. To show that pea seeds may respire anaerobically, fill a test-tube with mercury, and invert it over a dish of mercury. Introduce two or three soaked pea seeds into the mouth of the tube and keep the apparatus warm. The tube gradually fills with gas, and the level of the mercury falls. This gas has obviously been given off by the peas. If we now introduce a fragment of solid caustic potash into the tube we find that the gas is immediately absorbed. The mercury rises once more until it nearly fills the tube. From this we learn that the gas given off by the peas was carbon dioxide (for caustic potash absorbs this gas). There was no air in the test-tube at the beginning of the experiment. The peas have been respiring anaerobically.

It seems probable that anaerobic respiration may occur for a time in all plant cells that are deprived of oxygen. It often takes place in seeds before their thick coats (which keep out the air) are ruptured. It may occur in the centres of large fruits, in woody stems, &c.; in short, anywhere where oxygen cannot reach the respiring cells.

Facts such as these have led to the belief that the early stages of all respiratory processes are similar. The fuel is certainly not decomposed directly into carbon dioxide and water, as the equation given above would suggest. The process as it occurs in living cells is much more complex than that, the decomposition taking place in successive stages, so that various intermediate products are formed. It seems quite possible that all respiration begins anaerobically but, when the decomposition has reached a certain stage, the products formed are oxidized if the respiration is aerobic, this being the stage at which oxygen from the air is required.

RESPIRATION AND BREATHING. Our study of respiration, sometimes called 'tissue respiration', has shown that it is a biochemical process carried out by all protoplasm. We shall therefore not fall into the common error of confusing it with breathing. Breathing mechanisms are the arrangements by which respiring cells are supplied with oxygen and get rid of the waste substances formed. Breathing, i.e. inhalation and exhalation, are only the preliminary and final stages in the whole respiratory process. The study of these mechanisms will form the subject of succeeding chapters.

QUESTIONS ON CHAPTER XXI

For questions on respiration see questions to Chapter XXV,

CHAPTER XXII

HOW OXYGEN REACHES THE LIVING PROTOPLASM IN PLANTS

PLANTS AND ANIMALS COMPARED. An inspection of the plants and animals around us shows how different are the two in form (cp. p. 134). A plant (think of an oak tree) has a branching spreading body, and an enormous surface compared with its volume. An animal (think of a man or even an elephant) has a compact body, with a comparatively small surface and many deep-seated tissues. The plant is fixed and firmly rooted, the animal capable of locomotion. These differences in form are accompanied by great differences in the respiratory mechanisms. In the animal arrangements for bringing oxygen to cells which are far away from the surface must be much more elaborate than they are in plants.

RESPIRATORY MECHANISMS IN PLANTS

WATER PLANTS. If any organism lives totally immersed in water it must obviously absorb the oxygen it requires in solution. Submerged water plants have permeable skins (cp. p. 83) and can absorb oxygen through their whole surface. No elaborate respiratory mechanism is needed.

The algae are typical water plants, and, as we have learned already (Chapter IX), they are simpler in structure than are the plants which live on land. In addition to the algae, certain flowering plants are to be found growing in freshwater ponds and streams, e.g. water-buttercup, water-milfoil, pond-weed, arrowhead, &c. It seems likely that these are not to be thought of as true water plants. Their ancestors almost certainly lived on land, but these plants have become gradually adapted to life in water. Some live completely submerged; they possess very thin or very finely divided (and therefore absorptive) leaves; they have no cuticle and no stomates, stomates being organs for gaseous diffusion (cp. p. 105). We have here an example of a very widespread biological law. If

any part of a living organism is rendered useless by a change in the mode of life of that organism, the useless part tends to become reduced (vestigial) or even to disappear altogether. These submerged flowering plants provide further examples of the same rule. They usually have a very poorly developed conducting system; if the whole surface absorbs, it is obvious that conduction of water becomes, to a large extent, unnecessary. Their roots are similarly reduced to mere fixing, rather than absorbing organs, and possess few or no root-hairs; in some pond-weeds the root itself has almost entirely disappeared.

Another group of aquatic plants, as we shall see later (cp. p. 277), live partly submerged, but bring some organs above the water, where they are exposed to the air. Thus they are living in two very different environments (cp. Fig. 79), and obtain oxygen partly from the water and partly from the air.

Exercise. Examine and draw plants of milfoil, pondweed, &c. Examine also a transverse section of the stem of a water plant, as seen under the microscope, and compare the conducting system with the same system in the land plant, e.g. sunflower.

Notice that submerged water plants dry up very quickly when removed from the water, and consider how their impervious cuticle protects land plants from a similar catastrophe.

LAND PLANTS. Land plants obtain oxygen by diffusion from the surrounding atmosphere. Very rarely such plants (e.g. certain mosses) may absorb air over their whole surface. Usually, however, the epidermis of *herbaceous plants* and of the leaves and young stems of *woody plants* is cutinized (cp. p. 103) and hence impervious. But it is penetrated by stomata (cp. Fig. 24) and through these openings all the gases of the atmosphere can diffuse.

In *woody perennials* the epidermis of the young stem is gradually replaced by corky tissue (cp. Fig. 113). Cork is a very impervious and resistant substance (hence its use for closing bottles). It gives excellent protection to the underlying living cells; but such cells must be supplied with oxygen, and definite openings, called lenticels, are formed in the cork for this purpose.

LENTICELS.

Exercise. Examine and draw twigs of woody plants, e.g. horse-chestnut, beech, birch, elder, &c., and observe the tiny circular or oval patches scattered irregularly on the surface of the stems. These are lenticels, or respiratory pores by which oxygen reaches the underlying living cells. If we strip off the corky layer from a twig of elder we notice that the lenticels pass right through the cork, to communicate with the air-spaces which lie beneath.

Lenticels may also be recognized in an ordinary bottle cork (obtained from the cork oak). Notice that the cork is so cut that the lenticels pass across it, not down its length. The reason is obvious. Lenticels are formed on woody roots as well as on stems.

We learn that while water plants absorb oxygen through their whole surface, land plants have special apertures, *stomates* and lenticels, through which the oxygen necessary for respiration diffuses inwards and the carbon dioxide formed can escape (cp. p. 265).

INTERNAL DIFFUSION OF OXYGEN. Plant cells are not tightly packed. Internally there is always a ventilating system, formed of a labyrinth of tiny intercellular spaces. These all communicate with the external atmosphere through the stomates and lenticels.

Experiment 94. To demonstrate the existence of air in these internal air-spaces, dip leaves, portions of stem, woody twigs, &c., quickly into very hot water, and notice the escape of air bubbles. If the cut ends are covered with plasticine before immersion, the escape of this air through stomates and lenticels becomes even more clearly visible.

Being heated, the air in the internal ventilating system expands and escapes where it can.

We learn that oxygen, entering by stomates and lenticels, can circulate through the ventilating system of the plant, just as this gas, entering by the open windows of any building, diffuses through rooms and corridors. But in plants the protoplasm is not in direct contact with this internal atmosphere. Each protoplast is shut up within a cell wall. How does the oxygen actually reach the living, respiring protoplasm?

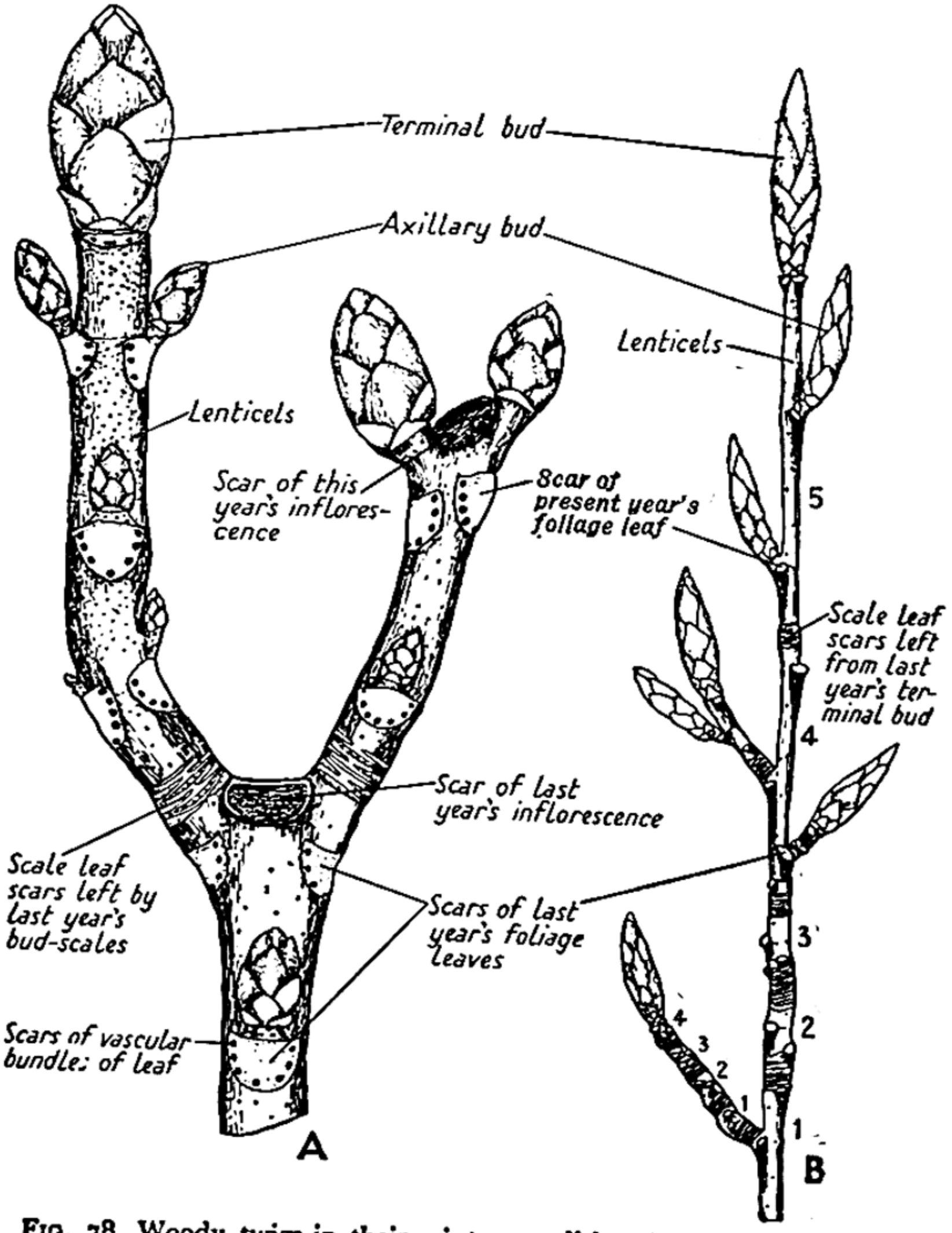


FIG. 78. Woody twigs in their winter condition (October). **A.** Horse-chestnut. **B.** Beech. 1–5, 1–4. Portions formed in successive years

OXYGEN PASSES THROUGH THE CELL WALL IN SOLUTION. We have already discovered that only substances in solution can pass through plant cell walls (cp. p. 81). This is as true of gases as it is of solid materials. In plants the cell walls abutting on the internal air-spaces are always wet. Oxygen gradually dissolves in this moisture and, in this condition, passes as required into the living protoplasm (cp. Chapter X). Waste materials (e.g. the carbon dioxide formed during respiration or the oxygen set free during photosynthesis) escape in a similar manner.

We see that, even in the land plant, gases (oxygen, carbon dioxide) must be dissolved in water before they can reach the protoplasm. In this important respect land and water plants are ultimately alike.

TWO ACCESSORY SOURCES OF OXYGEN. Before we leave the subject of the supply of oxygen to plant cells, we must remember two further sources of supply. Firstly, the green cell is assimilating during daylight and setting free oxygen as a waste product (cp. Chapter VI); some of this surplus is usually retained and used for respiration. Secondly, the root of the land plant absorbs water, and this water may contain a certain amount of oxygen, so that a little oxygen reaches the cells of the root in this way. Plants do not thrive in poorly aerated soils.

OXYGEN ESSENTIAL TO HEALTHY GROWTH. Oxygen is as essential to plants as to animals, as the following experiment will show.

Experiment 95. To show that oxygen is absolutely essential for healthy plant growth, cover two wet sponges with cress seeds. Suspend each sponge in a wide-mouthed bottle, having placed a little pyrogallic acid (which absorbs oxygen) at the bottom of one bottle. Cork both bottles tightly, and leave in a warm place. The seeds in the atmosphere devoid of oxygen grow hardly at all (anaerobic respiration may provide enough energy to make some just sprout). *Those supplied with oxygen grow well.*

MARSH AND WATER PLANTS. Some plants of pond, river, and marsh obtain oxygen (and carbon dioxide, cp. Chapter VI) from two sources. These pond and river plants are only partly

submerged; some of their leaves float on the surface of the water (e.g. water-lilies, starwort, &c.), or even stand up in the air (e.g. arrowhead).

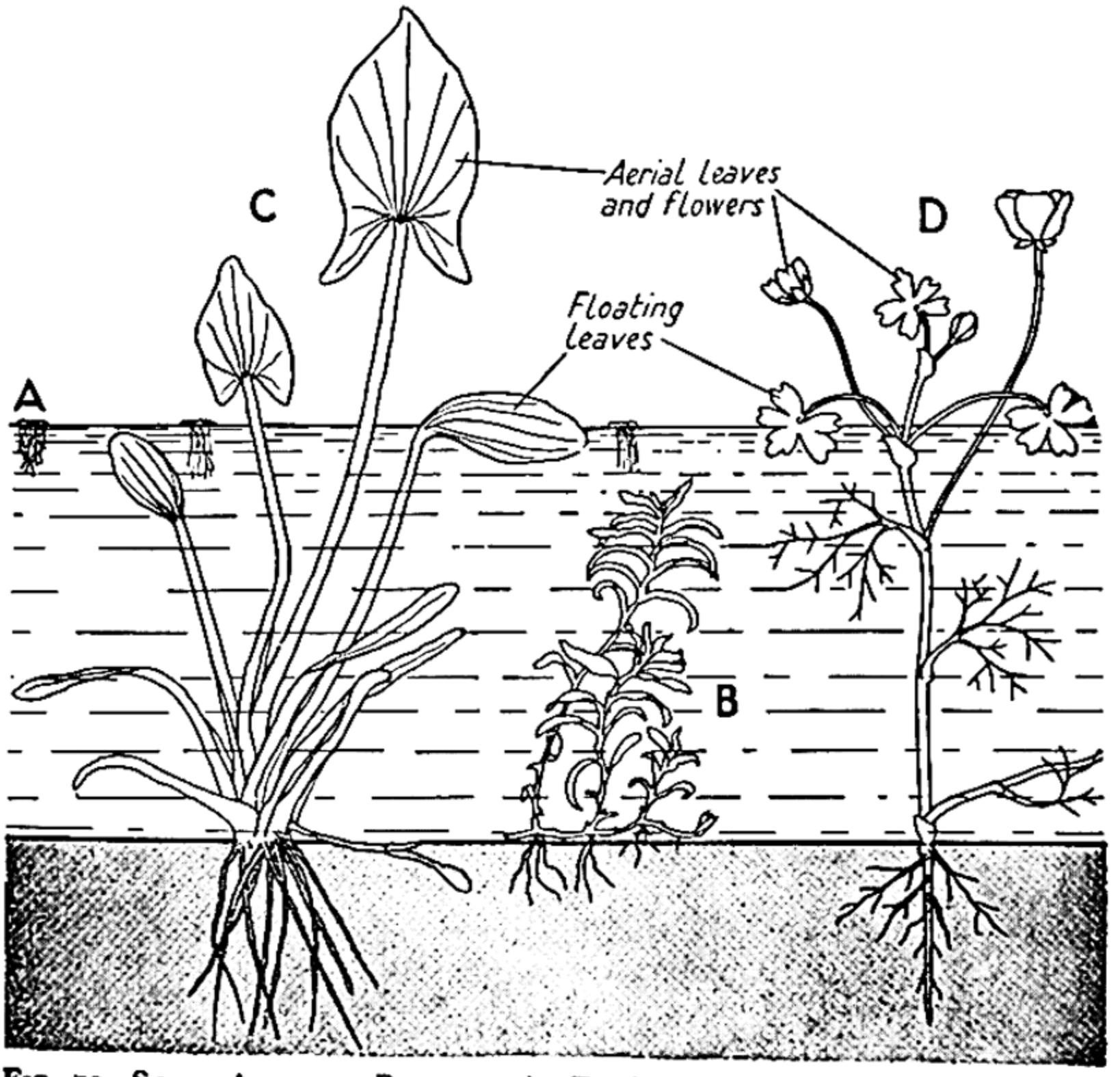


FIG. 79. SOME AQUATIC PLANTS. **A.** Duckweed, free-floating. **B.** Pondweed, completely submerged. **C.** Arrowhead. **D.** Water-crowfoot, each with submerged, floating, and aerial leaves. (All reduced)

The two types of leaf may be quite different in structure, conforming to the two environments. This is well seen in arrowhead and water-crowfoot (cp. Fig. 79).

Exercise. Examine a plant of the water-crowfoot. Notice the finely divided submerged leaves and compare these with the floating leaves. Remember that in the latter there are stomates in the upper epidermis, while the former have large air-spaces and no stomates.

Such a plant is truly amphibious. Its under-water parts absorb oxygen in solution. It enters the aerial parts by gaseous diffusion.

Air contains 21 per cent. of oxygen, i.e. in a litre of air there are 210 c.c. of oxygen. A litre of air-saturated water, on the other hand, only contains 5–10 c.c. of oxygen at ordinary temperatures. Hence many water plants experience difficulty

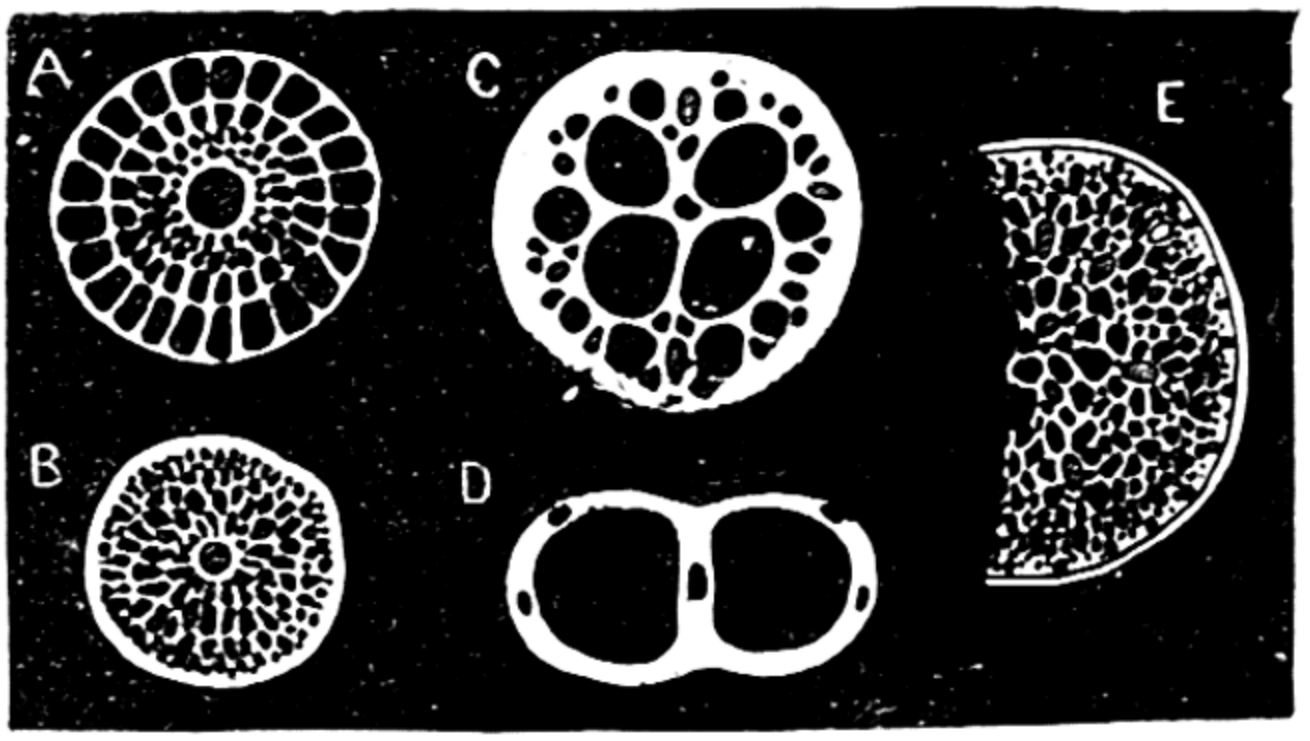


FIG. 80. Transverse sections of parts of water and marsh plants, to show air-spaces. (Cells are represented by the white portions; veins are shaded.) All × 5. **A.** Stem of pondweed. **B**, root, and, **C**, petiole, of white water-lily. **D.** Leaf of water-lobelia. **E.** Stem of flowering rush

in obtaining this gas. Marsh plants, whose lower parts are buried in stagnant mud, have to contend with the same difficulty.

Exercise. Examine transverse sections of the stems, roots, and leaves of typical water plants, such as floating pondweed (Potamogeton), white water-lily, &c., and try to discover how they differ from corresponding sections of land plants. In addition to the differences noted on pages 272 and 273, we find that such plants have unusually large air-spaces, often so large that they are visible with a lens or even to the naked eye.

AIR-SPACES AS A SIMPLE RESPIRATORY MECHANISM. These air-spaces not only give lightness and buoyancy to the tissues, but they are reservoirs of oxygen. Much of the waste oxygen formed during photosynthesis collects in these spaces, instead

of escaping. One observer found that the air in the intercellular spaces of pondweed might occasionally contain as much as 45 per cent. of oxygen. This oxygen can be used for respiration, the air-spaces acting as respiratory organs.

RESPIRATORY ORGANS IN MARSH PLANTS. Marsh plants often suffer from a shortage of oxygen, and a few such plants possess real respiratory organs. In the purple loosestrife, for example, special aerating tissue is developed on the submerged parts of the plant. This tissue, visible as white, spongy swellings on the surface of the root or shoot, brings oxygen to the living cells embedded in the stagnant water in which these plants live. Hence these swellings are respiratory in function.

In descriptions of tropical vegetation we often read of the impenetrable swamps that fringe the mouths of great rivers and line the shores of tropical seas. Mangroves are the typical plants of these water-sodden areas. They are trees endowed with special arrangements for catching oxygen.

The parts above ground have peculiar large lenticels which communicate with large intercellular spaces, while from their underground parts erect *respiratory roots* are sent up to the height of a foot or more above the surface of the swamp. These roots are true breathing organs. They radiate out in rows from the tree, making the jungle even more impenetrable; these rows of aerial roots mark the position of the horizontal submerged roots from which they spring, and to which they convey oxygen.

RESPIRATORY MECHANISMS IN PLANTS. A SUMMARY. With a few rare exceptions plants cannot be said to have any respiratory mechanisms. They depend on two physical facts for their oxygen supply:

1. The fact that oxygen is soluble in water and that, as a consequence, water in contact with air always contains some oxygen. This water, with the dissolved oxygen, can pass through the cellulose wall of the typical plant cell (cp. Chapter VIII).
2. The fact that all gases exhibit the phenomenon known as diffusion. Their molecules are always in motion, and tend to spread out, passing freely through quite small apertures,

such as stomates and lenticels, and remaining in constant motion even in the narrow intercellular spaces found in all plant tissues.

QUESTIONS ON CHAPTER XXII

For questions on respiration see the questions to Chapter XXV.

CHAPTER XXIII

BREATHING MECHANISMS IN ANIMALS

I. AQUATIC ANIMALS

ANIMALS WITHOUT A BREATHING MECHANISM. The simplest animals have no special respiratory mechanism. They absorb oxygen through their whole surface, as aquatic plants do. Such are the amoebas and other unicellular forms, called *Protozoa*; also the hydras, sea-anemones, jelly-fish, &c. (members of the Coelenterate group). In all these creatures the body wall is only two cells thick (cp. Fig. 31), and every cell of the body is near enough to the water to get the oxygen it requires directly; no special respiratory mechanism is necessary. There are some still higher forms which have no specialized breathing organs, but usually the higher types of aquatic animal possess special organs for oxygen absorption. These structures are called gills.

ANIMALS WITH GILLS. Gills are organs for facilitating the absorption of oxygen from water. Usually they are delicate folds of membrane which, projecting into the water, greatly increase the area of the surface through which oxygen can pass. (We may here recall the function of root-hairs in increasing the water-absorbing area of the root.) (Cp. p. 89.)

Very simple gills are seen in the common starfish, where they hang out into the water as numerous transparent processes from its back and sides. These are the simplest possible 'skin' or 'external' gills, and they aid in the absorption of oxygen.

Gills provide the large surface through which the necessary oxygen can be absorbed. But this oxygen must be carried to all the cells of the body, however far removed these may be from the source of supply, before it can be used for tissue respiration. How is this done?

TRANSPORT IN THE ANIMAL BODY

CIRCULATORY SYSTEMS. In all the higher animals, transport in the body is the work of the circulatory system. Although in some of the lower forms of life there is a circulating fluid

which is not very different from the water in which the animal lives, usually it is of complex composition, containing a respiratory pigment (e.g. haemoglobin; cp. p. 306) with a great affinity for oxygen. Such are the fluids that we call blood.

As the blood flows through the gills of aquatic animals it absorbs oxygen with the aid of its respiratory pigment; then it passes on, carrying this gas all over the body. The body cells use it for oxidizing food and releasing energy (tissue respiration). The blood passes back to the gills, where its oxygen supply is renewed. We may therefore regard the circulatory system of the higher animal as a part of the whole respiratory mechanism. It is, of course, carrying food as well as oxygen to the respiring cells.

ANIMALS WITH GILLS AND A CIRCULATORY SYSTEM. The fisherman's lobworm (cp. Fig. 81) is a very common object on the sandy seashore, where it lives in burrows. Its spirally coiled castings, seen at low tide, are formed of sand which the animal has swallowed in the course of its burrowing, and which has passed through its alimentary canal (cp. earthworm, p. 151).

Exercise. Examine one of these worms, which fishermen use for bait. Notice the following facts:

(*a*) The body, which is from 8 inches to a foot in length, is divided into many similar segments.

(*b*) The middle thirteen segments are clearly marked off from the front 'head' and the hinder 'tail' segments by the possession of tufts of branching reddish, thread-like processes. These outgrowths of the body wall are the gills, of which there are thirteen pairs on the underneath (ventral surface) of the animal.

(*c*) The red blood may be seen shining through the walls of the gill-filaments, for the animal has a simple circulatory system.

We have here, then, a respiratory mechanism with two sets of organs:

1. Gill-filaments, through which oxygen is absorbed and carbon dioxide eliminated.
2. A circulatory system, which carries this oxygen to all the living cells of the body and removes the waste materials resulting from their various activities.

In such an animal as the lobworm we have advanced a long way from that simple intake of oxygen through the whole surface which is found in the more primitive forms of aquatic life. But a third refinement of the breathing mechanism remains to be discussed. The animals so far described have been dependent on currents in the water, or on their own movements through it, for bringing up fresh supplies of oxygen

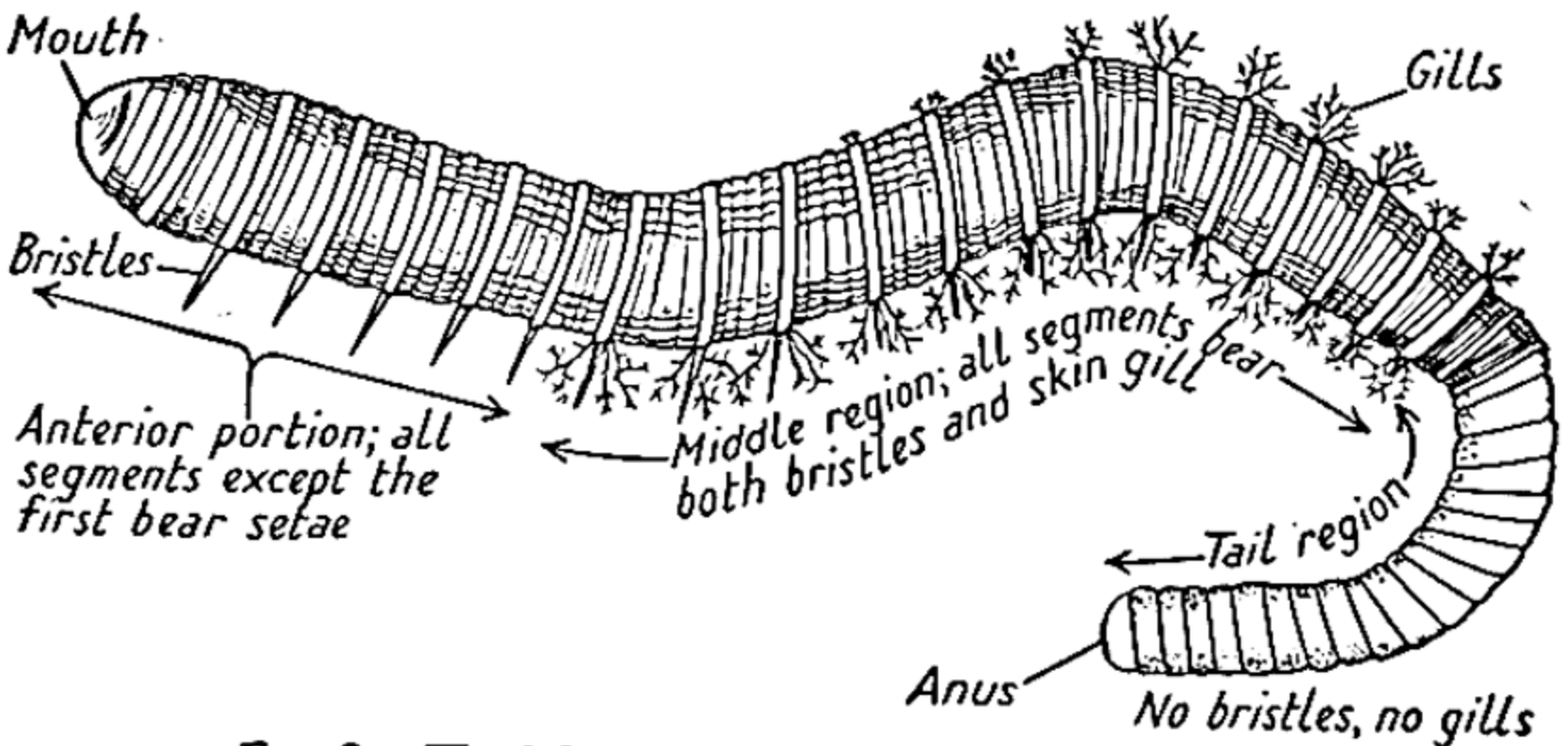


FIG. 81. The lobworm viewed slightly from the side

to the gills. The highest 'water breathers' are not restricted to this rough and ready method of obtaining supplies, but keep a continuous current of water flowing over their gills by their own definite and regular breathing movements.

ANIMALS WHO EXHIBIT DEFINITE BREATHING MOVEMENTS. This threefold system represents the highest type of aquatic respiratory mechanism. No written description will enable us to picture these inhalatory movements; they should be studied on the living animal whenever the opportunity occurs. Minnows, stickleback, goldfish, &c., can be kept in a small aquarium, and serve to illustrate the breathing movements of a typical fish.

Most interesting to watch are the *leg movements* of crabs, lobsters, crayfish, &c., by which they maintain a steady current of water over their gills. Outgrowths from the upper ends of one of their many pairs of legs continually bale water forward over the gill-filaments. These gills are not visible in the living

animals of this group, but are soon found in a dead specimen. They are brush-like structures on the sides of the thorax, covered by two armour-like plates of that hard crust (exo-skeleton) in which the whole animal is invested.

Experiment 96. By means of a pipette introduce a few particles of carmine or a little indian ink into the water just behind the gill covers of a live crayfish (in a shallow dish of water).

Find how long it takes for the coloured particles to be washed out again just behind the antennae of the animal.

Exercise. Examine a crayfish or lobster, both living and dead. Find the hard carapace which covers the gills. Remove a gill, and draw it under water.

THE RESPIRATORY MECHANISM OF A TYPICAL FISH

BREATHING MOVEMENTS. Fishes are masters of river and ocean, as are mammals of the land, and birds of the air. Watch a minnow or goldfish in an aquarium, observe the continual opening and shutting of the mouth, and time these—its breathing movements. The mouth being open and its floor depressed, the cavity fills with water. It then closes the mouth and entrance to the gullet (food canal), at the same time raising the floor. In this manner a current of water is driven over the gill-filaments. These structures cannot be seen in the living goldfish or minnow; they are on the sides of the throat, but are covered by a protective operculum, which can be seen to move gently (cp. Fig. 84).

THE GILLS OF FISHES. In all fishes the back of the throat (the pharynx) is pierced by a series of gill-slits, usually four or five, through which the respiratory current flows. Between these slits are gill-arches, supported by bars of cartilage which form a part of the skeleton. The membrane covering each arch is thrown on both sides into numerous folds—the gill-filaments (cp. Fig. 82)—which are the actual organs of gaseous exchange.

There are roughly two types of gill structure in fishes. In the more familiar *bony* fishes, such as haddock, cod, goldfish, &c., the partitions (septa) which separate the actual gill-clefts are so thin that they are completely masked by the gill-filaments. The whole gill-apparatus in these fishes is covered and

protected by an operculum, which has a folded membrane, the branchiostegal membrane, along its outer and posterior edge. This can be forced against the side of the fish so as to close the aperture while water is being inhaled (cp. Fig. 84).

In the *cartilaginous* fishes the gill-slits are uncovered, and hence visible on the sides of the throat (cp. Fig. 85). The breathing

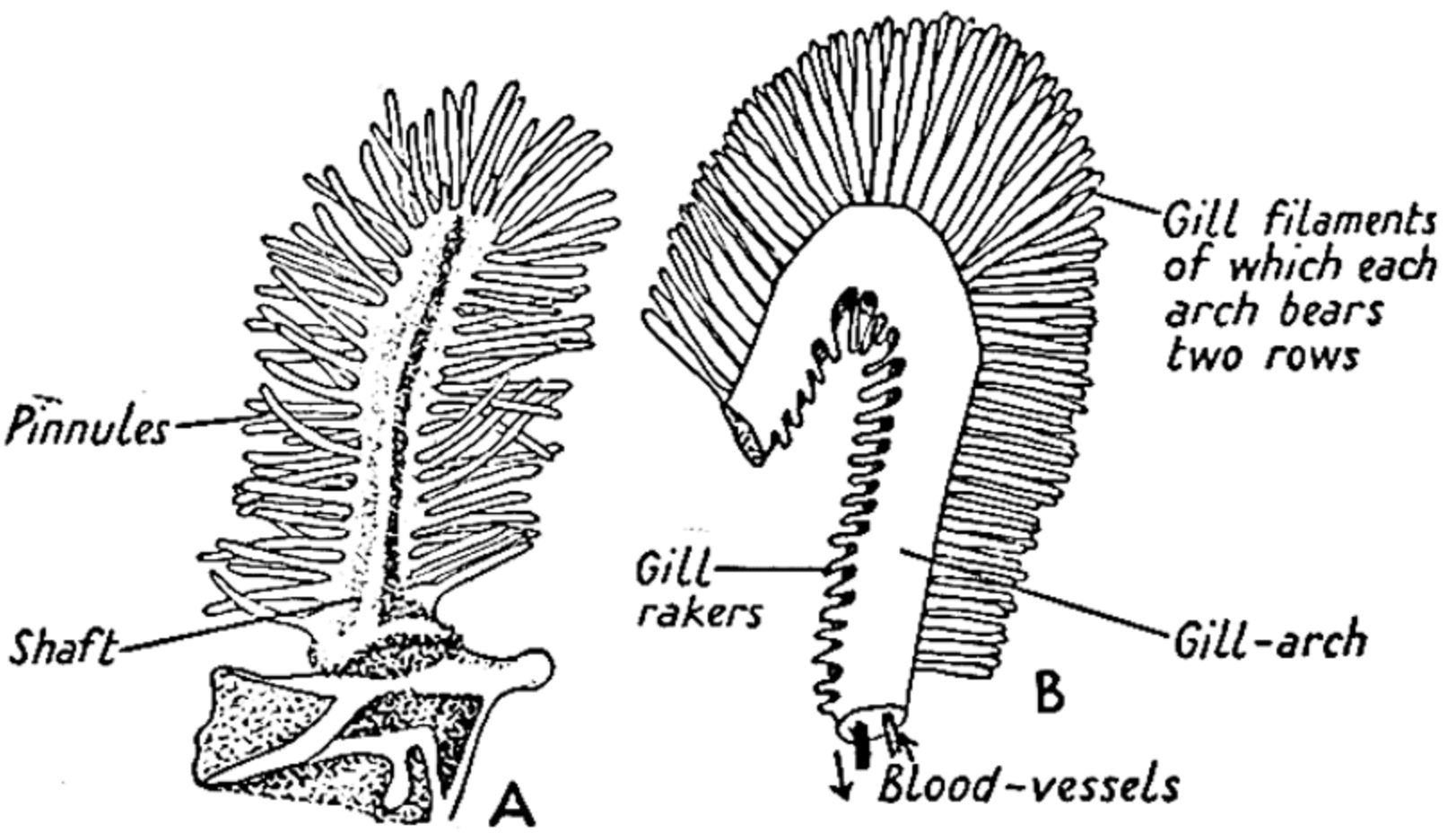


FIG. 82. ILLUSTRATING THE FORMS OF GILLS. **A.** One gill of crayfish (after Dakin). **B.** Gill of a bony fish, seen from the side

movements of such a fish (e.g. dogfish, skate, &c.) are most interesting and should be studied in some marine aquarium.

THE FISH CIRCULATION. A fish, like every vertebrate animal, possesses a heart which by its contractions keeps the blood in motion. This heart has two main chambers, an auricle and a ventricle; between the two are valves which allow the blood to flow freely forward, but close behind it and prevent any backward flow.

The blood is driven by the heart through the fine capillary vessels in the gill-filaments, where it is only separated from the respiratory current of water by very thin membranes. Dissolved gases are exchanged between the blood and the sea-water, oxygen being absorbed and carbon dioxide excreted. The blood, now rich in oxygen, passes on to all parts of the

body, the larger blood-vessels eventually breaking up into fine capillaries among the tissue cells.

Here once more there is an exchange of dissolved substances, the blood giving oxygen (and food, cp. p. 261) to the tissue

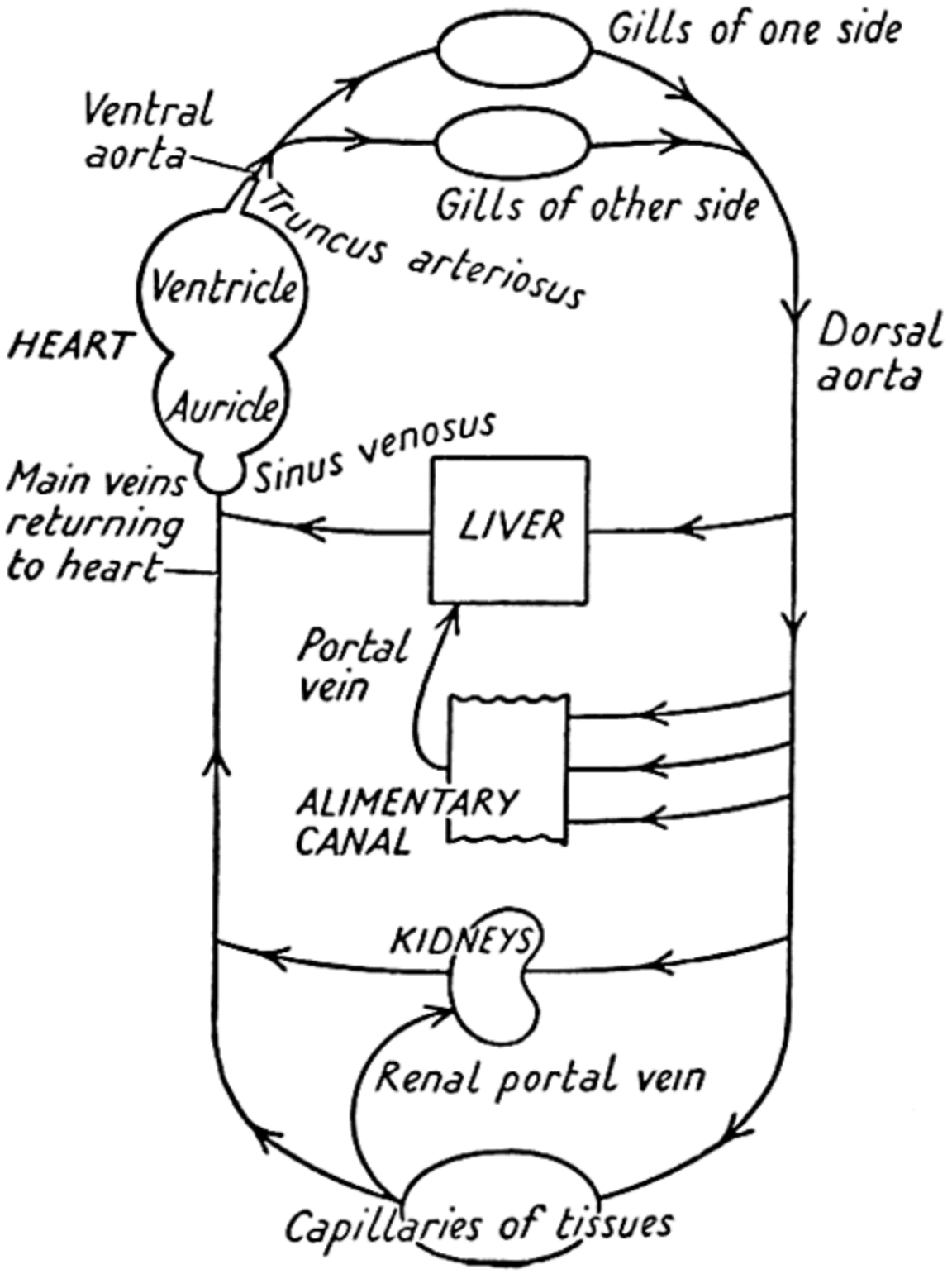


FIG. 83. Circulation of the fish

cells and removing waste products from them. The capillaries join up once more to form veins and the blood is taken to the heart, which contains only deoxygenated blood. The heart contracts and drives this blood once more into the gills.

We see that by such a circulatory system the oxygen absorbed from the sea-water in the organ of respiration (the gills) is carried by the blood to the body cells, where it is required for tissue respiration. Each cell oxidizes enough food to supply the energy for its various activities.

THE EXTERNAL FEATURES AND METHOD OF LOCOMOTION OF A TYPICAL FISH.

Exercise. Observe and make sketches to illustrate the structure of any bony fish, such as a haddock, sprat, or minnow. Notice the smooth torpedo-like body, divided into head, trunk, and tail. Its stream-lined shape fits it admirably for easy motion through water.

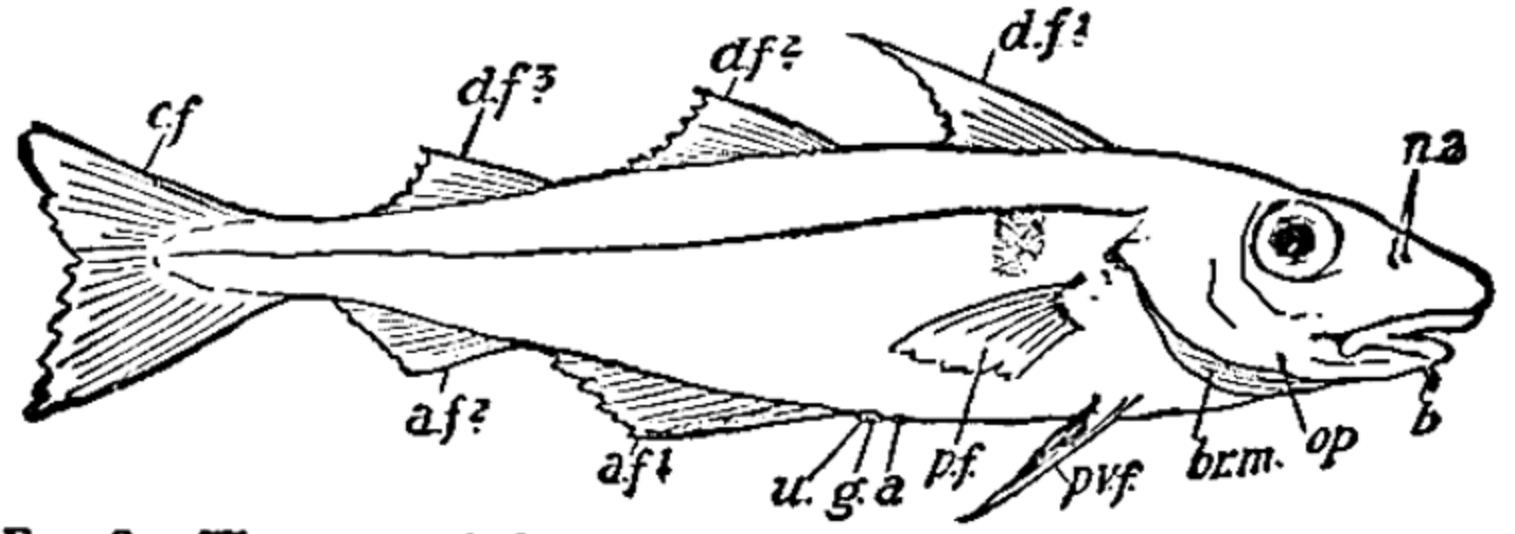


FIG. 84. The external features of a bony fish (haddock). Observe the nasal aperatures (*n.a.*), the eye, the operculum (*op.*), and branchiostegal membrane (*br.m.*) covering the gills; paired fins (pectoral, *pf.*, and pelvic, *pv.f.*, the latter being very far forward); median fins (*a.f.*¹, *a.f.*², *d.f.*¹, *d.f.*²) including the caudal fin; the anal (*a*), reproductive (*g*), and urinary (*u*) apertures. In this region the trunk (with coelom) merges into the solid, muscular tail

Observe the large mouth, edged by folds which enable it to be very tightly shut; the two nostrils, each with a double aperture (these do not communicate with the mouth, i.e. there are no internal nares); the lidless eyes, covered by a thin, transparent skin. No ears are visible, there are only internal ears (cp. p. 234), and these are embedded in the bones of the skull.

Now find the anal, reproductive, and excretory apertures, all very close together on the ventral surface. These mark the merging of the hollow trunk (containing the body cavity or coelom) into the solid, muscular tail. The tail is the chief organ of locomotion. The fish swims by twisting it from side to side with a somewhat screw-like action. (Roughly we may compare the movement with that employed to propel a rowing-boat by means of a single oar at the stern.)

Fins. The tail ends in a large median tail fin, typically two-lobed. There are several other median fins on both dorsal and ventral surfaces (the exact number and arrangement vary from species to species). In addition all fish have two sets of paired fins—pectoral and pelvic—which correspond in position to the paired limbs of land

vertebrates. Find these fins and observe their structure. All fins are formed of delicate folds of skin stiffened by little rods of skeletal tissue. They are all used in swimming. The tail fin moves with the tail, acting as a 'screw' propeller and also as a rudder for steering. The paired fins may also be used for steering and even, especially during slow movement, for swimming. They are chiefly used, however, for ascending and descending and to preserve balance. The median fins act somewhat like the keel of a boat: they make the fish deeper (as compared with its width) and help it to maintain a straight course, preventing sideways slip.



FIG. 85. The external features of a cartilaginous fish (dogfish). Observe the mouth, eye, spiracle, gill-clefts opening directly to exterior; paired fins (*pl.f.* is the right pelvic fin, the right pectoral fin is in front of it); median fins including the caudal fin (*c.f.*); and the long, solid, muscular tail (extending from *pl.f.* to posterior end)

Observe next the very characteristic overlapping scales, kept moist and slippery by mucous glands in the skin, which give the fish so smooth a surface. These grow with the growth of the animal, and are often ringed. These rings are used by fishermen (e.g. salmon fishers) to estimate the age of a catch, since a new one grows every year.

Finally, study the gill-apparatus. Observe the operculum and the branchiostegal membrane along its edge. Raise it and notice and count the gill-clefts with their gill-filaments. Pass a seeker or a glass rod through a gill-cleft into the mouth. Open the mouth, observe and sketch the internal aspect of the gill-slits, and notice the gill-rakers which strain the water and prevent food from escaping in the respiratory current. Notice the small, fixed tongue and the many small teeth. Observe the arrangement of the latter. Do they only edge the jaws, as do those of a mammal?

Now make a similar examination of the external appearance and gill-slits of a cartilaginous fish (e.g. dogfish or skate). Notice particularly the absence of an operculum, the exposed gill-slits, the spiracles, and the sharp tooth-like scales.

Exercises

Obtain the head and shoulders of a cod or other large, bony fish. Observe the lidless eyes, nasal apertures, mouth, scales, teeth, &c., as before. Identify the operculum and the branchiostegal membrane. Lift it and examine and draw the gill-apparatus. Look inside the mouth, count the gill-slits on each side, identify the gill-filaments and the gill-rakers. Cut out one of the gills carefully, place it in water in a watch-glass, and draw.

Observe the movements of bony and cartilaginous fishes in an aquarium, and compare their actual movements with the account given in the previous exercise. Though this general account is true, there are marked individual differences between the different species. Do not therefore rely on this description, but observe the movements of some given fish for yourself.

Observe also their respiratory movements and make careful notes of what you see. Compare these movements in bony and cartilaginous fishes.

RESPIRATORY MECHANISMS IN AQUATIC ANIMALS. A SUMMARY.

As we pass up the scale of life from the simple to the more complex animals, we find breathing mechanisms becoming more elaborate, as do digestive organs (cp. p. 159), nervous systems (cp. p. 208), &c. We have examined four types of breathing mechanism in aquatic animals:

A. Oxygen is often absorbed through the whole surface of the animal, e.g. Amoeba, Hydra, jelly-fish.

B. Some animals have simple 'skin-gills', which increase the absorptive surface, e.g. starfish.

C. Some have gills combined with a circulatory system. Oxygen is picked up by the blood as it flows through the gills, and is then carried on to the body cells, e.g. lobworm, Nereis.

D. The most advanced aquatic animals keep a current of water flowing over their gills by definite inhalatory movements. The water brings up fresh supplies of oxygen. This oxygen passes into the blood as it flows through the gill-filaments and is carried away to the internal cells for their respiration, e.g. crabs, lobsters, shrimps, fishes, &c.

Many fishes lead extremely active lives. Marked fishes have been recaptured hundreds of miles from the place where they were released after marking. The story of the journey, half across the world, on which the European eel sets out when it has reached maturity is told in another chapter. Watch the fish in an aquarium and notice how active some species are. Such activity would be impossible without an efficient mechanism for supplying oxygen to the living protoplasm.

QUESTIONS ON CHAPTER XXIII

For questions on this chapter see the questions to Chapter XXV.

CHAPTER XXIV

BREATHING MECHANISMS IN ANIMALS (*continued*)

II. LAND ANIMALS

RESPIRATION OF LAND ANIMALS. Land animals capture oxygen in gaseous form. Like aquatic animals, they show great variation in their breathing mechanisms, some of these being extremely simple, others much more elaborate.

ANIMALS WITH NO SPECIALIZED RESPIRATORY MECHANISM. Some land animals possess no special breathing organs. This is not only true of minute forms of life; even such a comparatively highly organized creature as the common earthworm has no definite organ for absorbing oxygen. It has a wet, slippery skin, kept permanently moist by secretory cells which exude the necessary liquid (cp. p. 154). Oxygen dissolves in this liquid and passes through the skin, being absorbed by the whole surface of the animal. Just under the skin is a network of fine capillaries, through which flows the blood, a liquid coloured red by haemoglobin (cp. p. 306), which, in this animal, is dissolved in the plasma. The blood picks up oxygen here and distributes it wherever it is required. We realize why earthworms can only flourish in moist soils.

TRACHEAE. Insects are the most numerous of all air-breathing animals, and they often lead extremely active lives.

'They walk, run and jump with the quadrupeds; they fly with the birds; they glide with the serpent and swim with the fish.'

Rather like a lobster or crayfish in structure, the typical insect has a very different respiratory mechanism. In the lobster, as we have seen, the blood is brought near to the oxygen of the surrounding water in gill-filaments, over which the respiratory current is kept flowing by the movement of a pair of specialized legs. In the insect gaseous oxygen penetrates to every part of the body in a system of branching tubes, called *tracheae*, which represent delicate in-pushings of the outer wall of the body. The tracheae open on the surface of the animal, these openings

being called *spiracles*. In the typical insect they are quite definite in arrangement. There are seldom more than two pairs on the thorax; on the abdomen there are usually from six to eight pairs; occasionally there may be as many as ten (cp. Fig. 86).

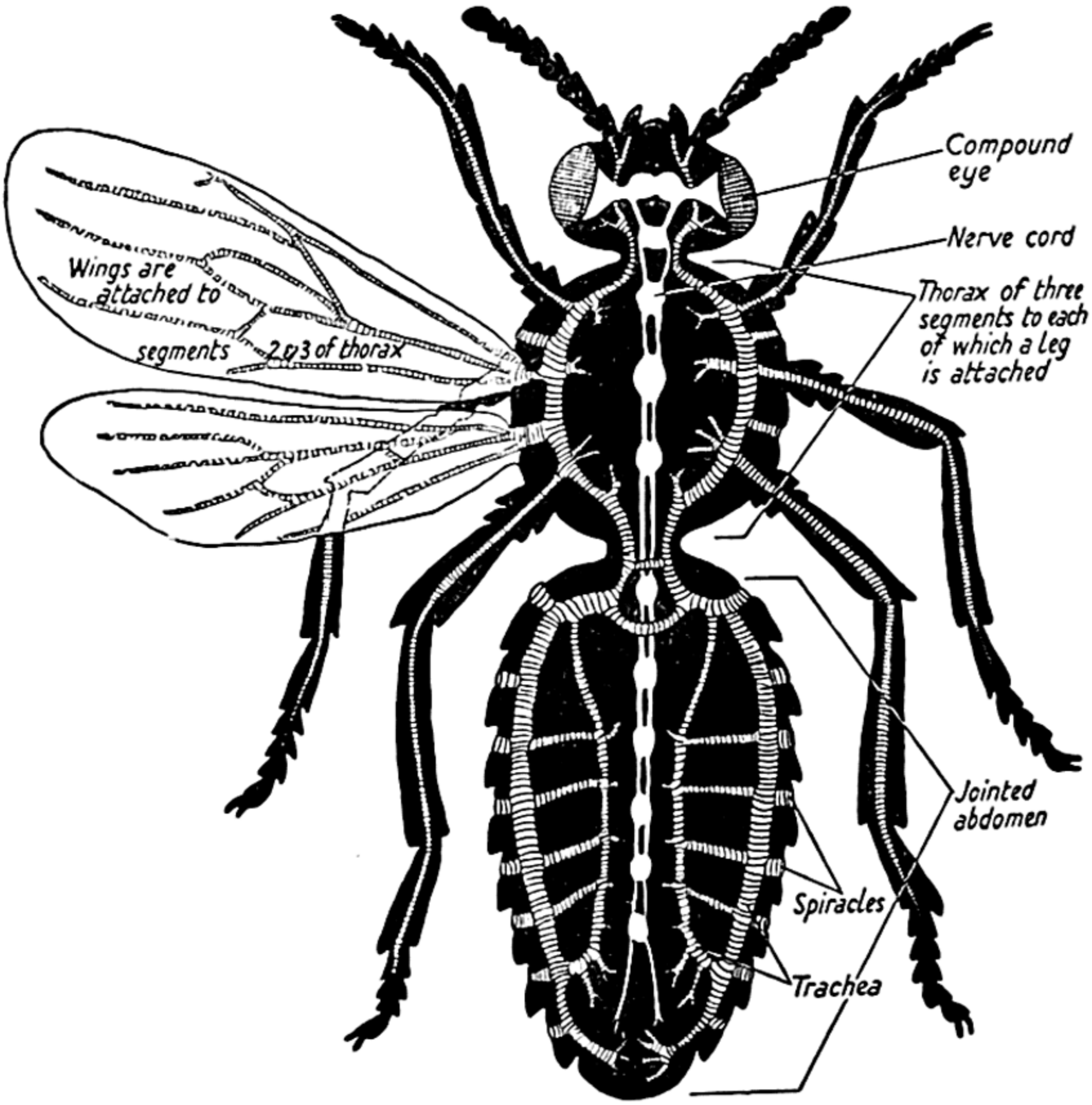


FIG. 86. Structure of a typical insect

The walls of the tracheae have spiral thickenings, which prevent them from collapsing and give them a very characteristic appearance under the microscope (cp. Fig. 87). They branch continuously and eventually end in very delicate tubules, the tracheoles, where the actual giving up of oxygen to the tissue cells occurs.

There are special respiratory muscles in the abdominal wall

whose movements can be observed in the living insect. In the dragon-fly these movements occur about thirty times a minute. They serve to contract the tracheae and to drive out the contained air. Then the muscles relax and more air enters.

We see then that, to meet the demands of its very active

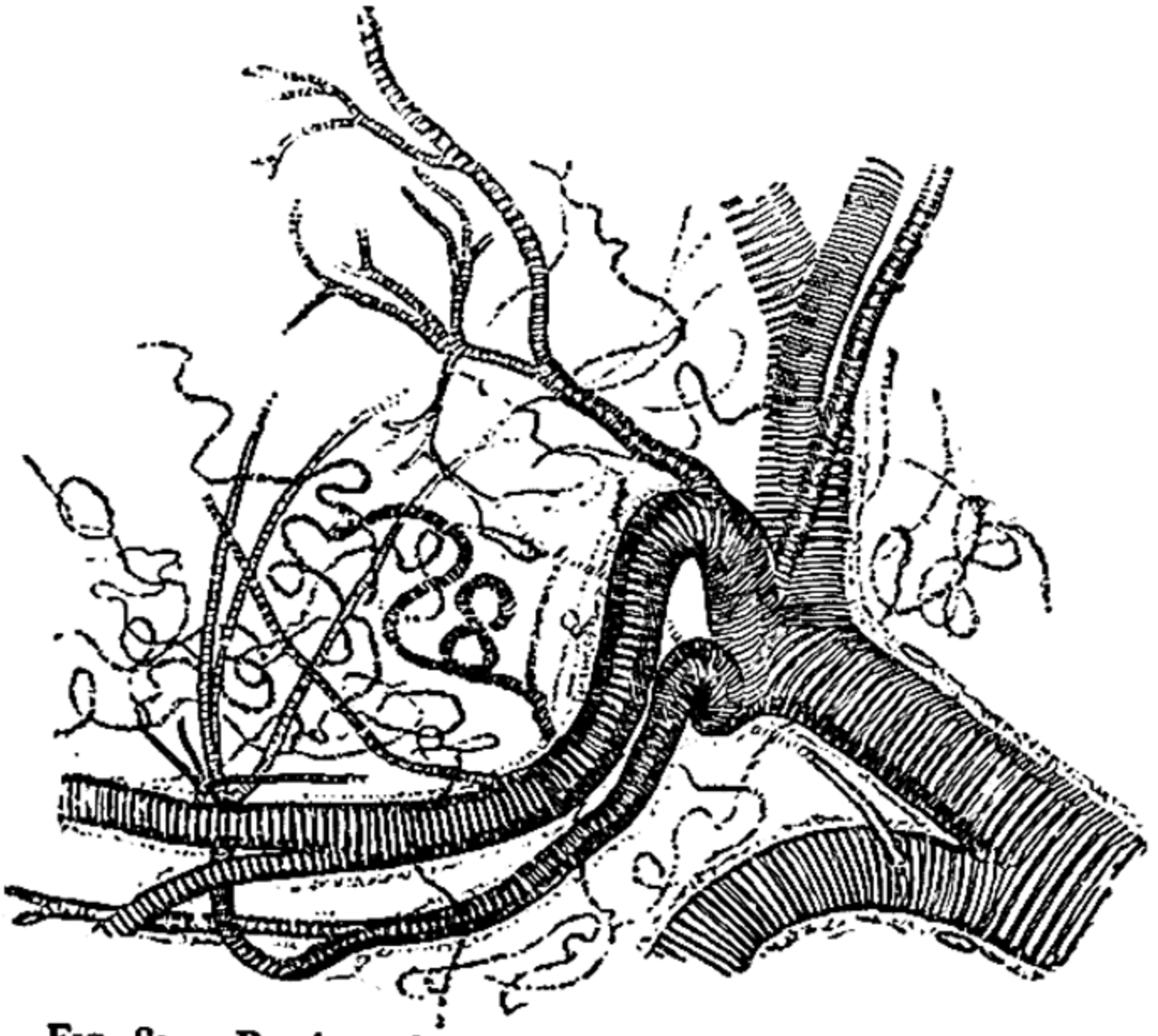


FIG. 87. Portion of the trachea of a cockroach seen under the microscope

life, an insect possesses an extremely specialized breathing mechanism by which air is introduced all over its body.

Exercise. Examine and draw typical insects; for example, a butterfly, a cockroach, a dragon-fly, a fly. Notice the division of the body into head, thorax, and abdomen (cp. p. 157). Look for the openings of the spiracles, which are usually found on the sides of the body, between the segments. They are often protected by hairs or bristles, so that foreign particles shall not enter and block the opening.

A COMPARISON OF THE MECHANISM OF RESPIRATION IN THE INSECT AND THE FLOWERING PLANT. In both these very diverse forms of life oxygen is passed in gaseous form into all the recesses of the tissues. It is therefore interesting to compare the two mechanisms, which, though

broadly similar, exhibit very important differences. In making this comparison let us keep in mind the passive life of the plant and the very active life of the typical insect.

(1) In the plant the external openings, stomates and lenticels, are irregularly scattered over the surface. In the insect the spiracles are few in number and definite in arrangement.

(2) In the plant the openings merely lead into irregular chinks and cavities between individual cells. In insects the tracheal tubes have a very characteristic structure with spiral thickenings; they branch continually and end blindly among the tissue cells.

(3) The plant depends on gaseous diffusion only, the insect on definite respiratory movements which keep the air in circulation.

(4) In both cases the oxygen passes into the protoplasm of the cells in solution. In the plant it dissolves in the wet cell-walls; in the insect the narrowest tracheoles appear to be filled with fluid.

LUNGS. All the higher animals are air-breathers, absorbing oxygen by means of lungs. These organs are always paired, and so constructed as to present as large a surface as possible to the air. The lung itself is merely an elastic bag; air is driven rhythmically in and out of this bag by the breathing movements of the animal. Blood, circulating in the network of capillaries in the wall of the lung, absorbs oxygen from the air there and carries it off to the tissues; at the same time it gives up its waste carbon dioxide. The lung, like the gill, indeed like every respiratory organ found in the animal body, is a structure in which the internal fluids of the body, in most cases the blood, are brought near to the source of oxygen over as large an area as possible. Air is able to pass in and out of the lungs freely, since they communicate by means of a trachea (or windpipe) with the back of the throat, and so through mouth and nose with the external atmosphere (cp. Figs. 3, 4).

Amphibians, reptiles, birds, and mammals all possess lungs. Even when such animals live largely in water, as do crocodiles, alligators, marine turtles, sea-snakes, &c., among reptiles, and seals, whales, sea-lions, porpoises, &c., among mammals, they must come to the surface to breathe.

A lung of comparatively simple type is seen in the frog; in the mammals (man, rabbit, &c.), both the lung itself (cp.

Figs. 4, 88) and the whole respiratory tract have reached a much higher stage of development. We start, therefore, by examining these structures in the frog.

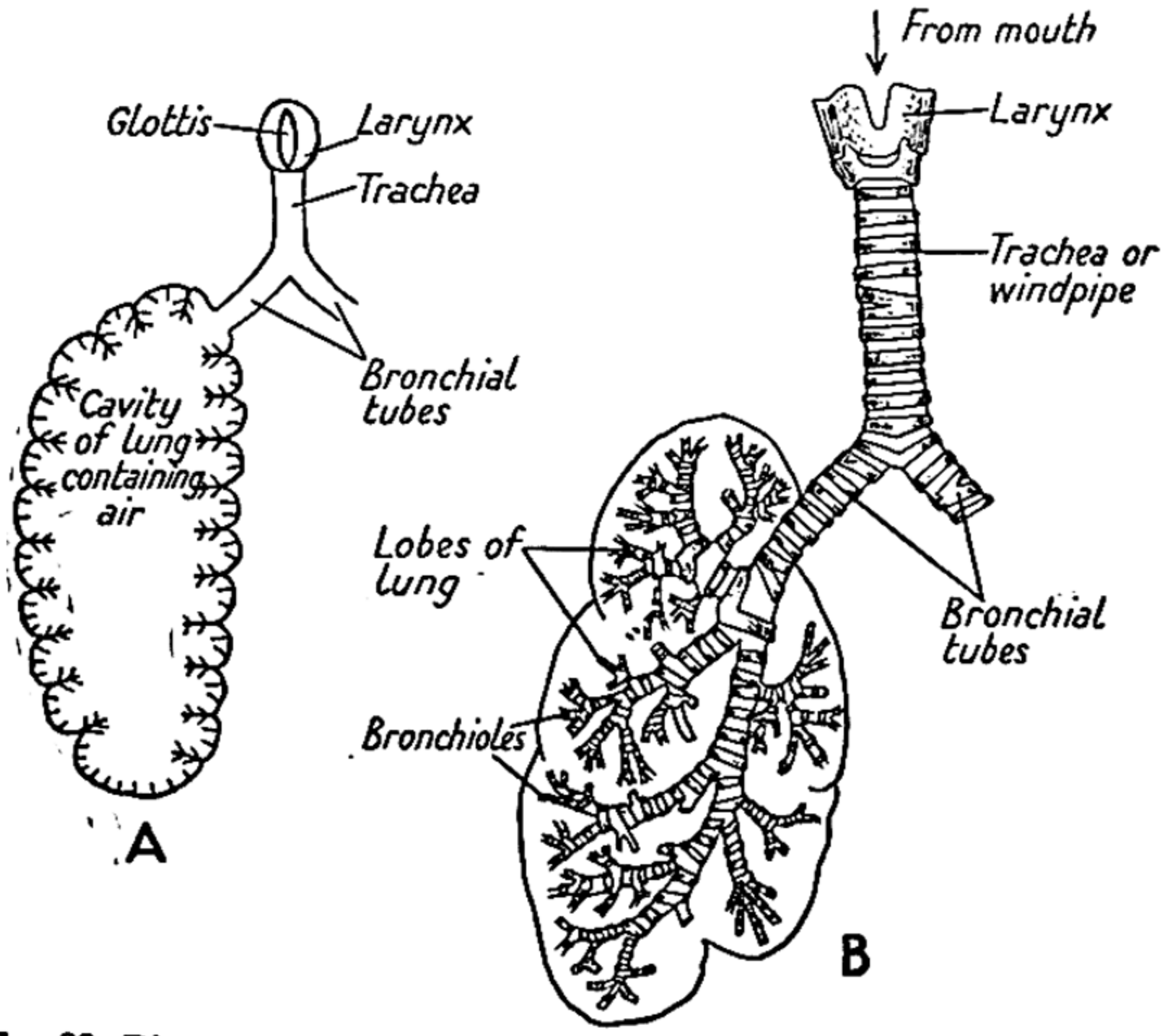


FIG. 88. Diagrams showing the structure of lungs and bronchial tubes in (A) an amphibian, e.g. frog (somewhat enlarged), and in (B) a mammal, e.g. rabbit, man (somewhat reduced)

THE RESPIRATORY ORGANS OF THE FROG. The frog only has lungs in its adult stage, and is never entirely dependent on them for the oxygen it needs, retaining all through life the power of absorbing this gas through its skin and through the lining of the mouth (cp. p. 323), as well as in the lungs.

These lungs are hollow thin-walled sacs, the amount of surface exposed to the air being increased by in-folding of the wall (cp. Fig. 88 A). The trachea or windpipe is very short, and

leads to the glottis, a slit-like opening in the floor of the mouth. The circulation and respiratory movements are fully described in the next chapter.

RESPIRATION IN MAMMALS

THE LUNGS OF THE MAMMAL. In the mammal the folding of the lungs is carried to a great extreme. It has been calculated that in man there is about 1,000 sq. ft. of lung surface in contact with the air. When we remember that the whole area of a man's skin is only about one-thirtieth of this, we see how well adapted this lung is for exposing a large surface to the air, while the organ itself is tucked away within the body, where it is protected from injury.

Exercise. Examine and draw the lungs and windpipe (trachea) of a rabbit or, better still, of a sheep. These latter can sometimes be obtained from the butcher. Notice that the trachea is stiffened by C-shaped rings of cartilage ('gristle'). The tube is thus kept always open, so that air has free access to the lungs. At the top of the trachea is the larynx, or voice-box. The opening of the larynx into the back of the mouth (the glottis) is protected by a lid-like epiglottis, which is found just behind the root of the tongue. Slit open the larynx and find the vocal chords.

At its lower end the trachea divides into two bronchial tubes. These pass into the pink, spongy substance of the two lungs (sold as 'lights' by the butcher). Within the lungs the bronchial tubes divide and divide again. The larger tubules are still supported by small rings of cartilage. Each tubule finally ends in an air-space or air-sac, out of which lead a number of blind alveoli, which can only be seen with the microscope. The whole structure may be compared to a bunch of grapes, in which the main stem corresponds to a bronchus, the branch stems to the bronchioles, the grapes to the alveoli.

It is in the walls of the alveoli that the actual exchange of gases occurs. Capillary blood-vessels ramify in their delicate walls, and as the blood, coming from the heart, flows through these capillaries it picks up oxygen and loses its surplus carbon dioxide and water vapour.

THE CIRCULATORY SYSTEM IN A MAMMAL. The circulation of mammals is very different from that found in the fish. In the

fish the heart contains deoxygenated blood, which it pumps through the gills, and thence over the body (cp. Fig. 83). It is obvious that the pressure caused by the heart-beat will have been largely lost by the time the blood has been squeezed through the narrow gill-capillaries.

In the mammal the heart likewise drives deoxygenated blood

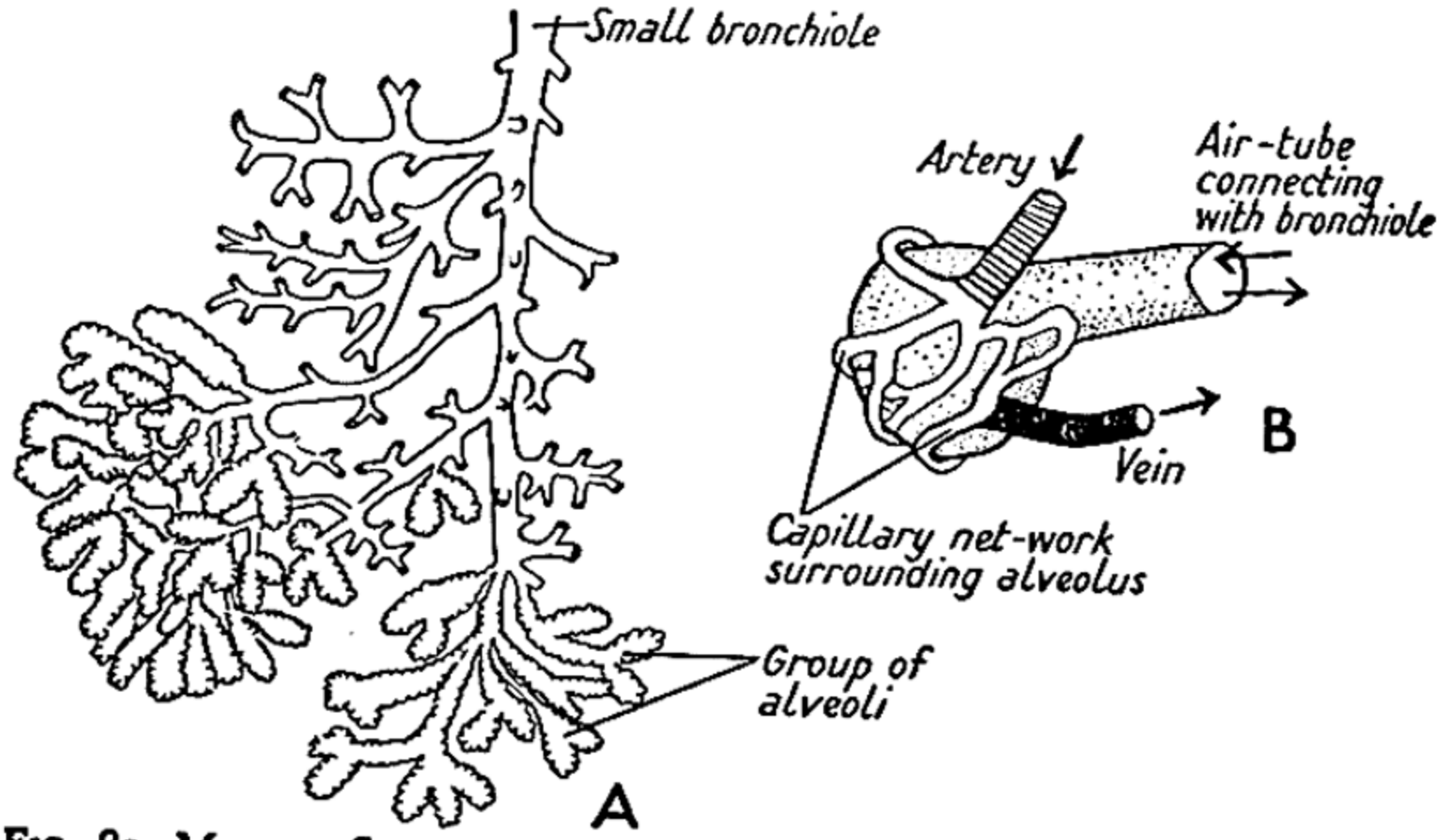


FIG. 89. MINUTE STRUCTURE OF LUNG IN MAMMAL. **A.** Showing how the bronchioles end in air-sacs, the walls of these air-sacs being studded with alveoli (highly magnified). **B.** One alveolus, more highly magnified, showing its blood-supply

through the capillaries of the respiratory organ, i.e. of the lung. But, when its oxygen supply has been renewed, this blood does not pass on directly to the tissues. It is returned to the heart, and is driven thence all over the body. The advantage of this system is obvious. One stroke of the pump sends the deoxygenated blood through the lungs; another powerful stroke is given to drive the oxygenated blood all over the body.

In the heart this deoxygenated blood is kept quite separate from the oxygenated, although both kinds are passing through it simultaneously. This is possible as the heart is divided into a right and left side. There is a right auricle leading into a

right ventricle, and a left auricle which leads into the left ventricle; but there is no direct communication between the two sides. Hence the general course of the circulation is as shown below.

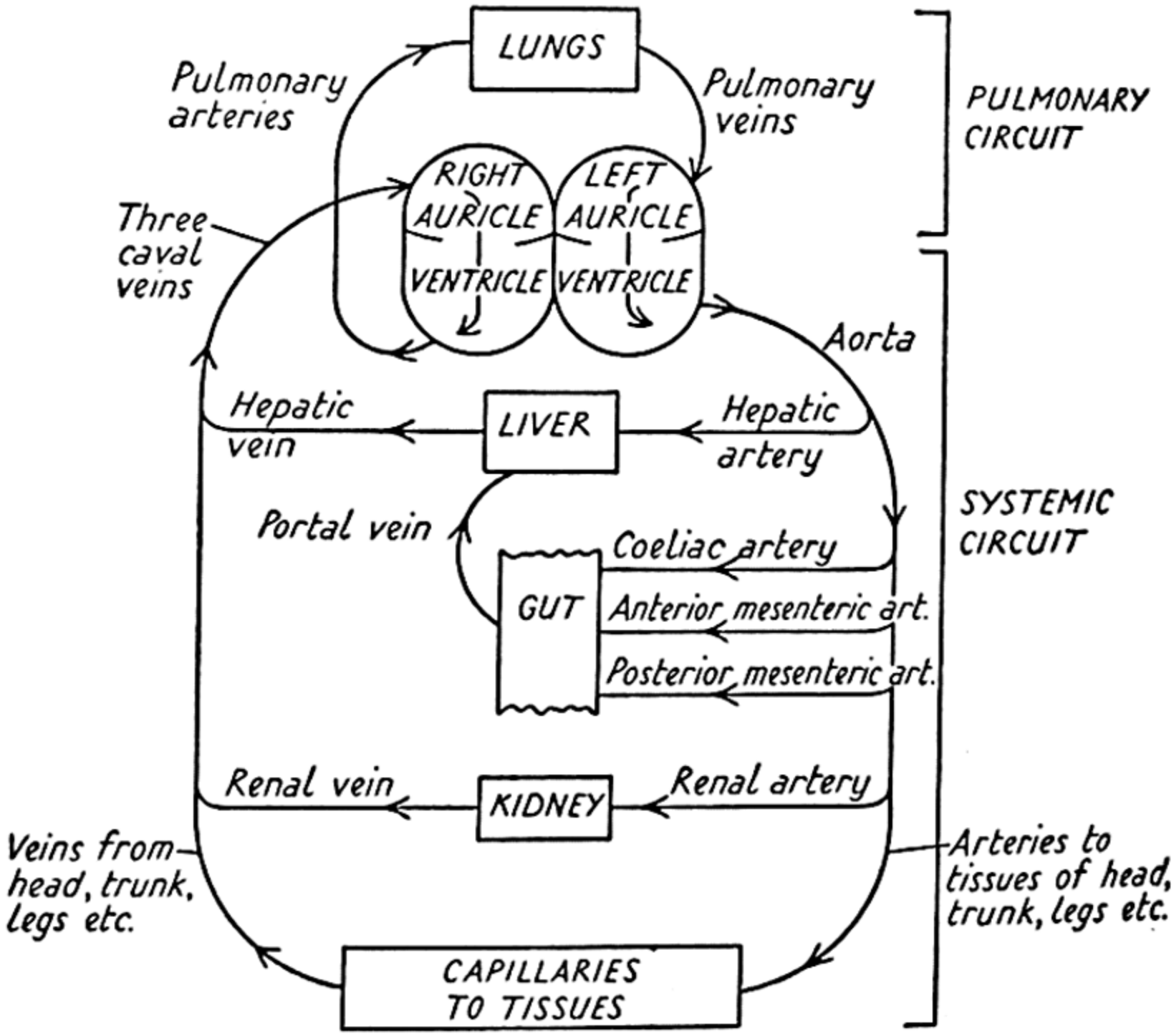


Fig. 90. Showing the general course of the circulation in a mammal. Notice the separate pulmonary and systemic circuits

Three vena cavas (two in sheep and man, as the two anterior vena cavas unite before they enter the heart) return the deoxygenated blood from the tissues to the right auricle. The aorta, which leaves the left ventricle, gives off many branches which carry oxygenated blood to all the tissues except those of the lungs. The pulmonary arteries and veins take blood to and from the lungs respectively (cp. Figs. 90, 91).

There is thus a double circulation in all mammals.

(*a*) Letters to right—

e.c. External carotid artery.
i.c. Internal carotid artery.
e.j. External jugular vein.
scl.a. Subclavian artery.
scl.v. Subclavian vein.
p.a. Pulmonary artery (cut short).
p.v. Pulmonary vein.
L.A. Left auricle.
L.V. Left ventricle.
d.ao. Dorsal aorta.
h.v. Hepatic veins.
c. Coeliac artery.
a.m. Anterior mesenteric artery.
s.r.b. Adrenal body.
l.r.a. Left renal artery.
l.r.v. Left renal vein.
K. Kidney.
spm. Spermatic artery (vein below).
p.m. Posterior mesenteric artery.
c.il.a. Common iliac artery.

(*b*) Letters to left—

p.f. and *a.f.* Posterior and anterior facial veins.
e.j. External jugular vein.
i.j. Internal jugular vein.
R.Scl. Right subclavian artery
S.V.C. Superior vena cava.
R.A. Right auricle.
R.V. Right ventricle.
I.V.C. Inferior vena cava.
r.r.a. Right renal artery.
r.r.v. Right renal vein.
s.r.b. Adrenal body.
spm. Spermatic artery and vein.
il. Ilio-lumbar vein.
f.v. Femoral or external iliac vein.
i.il.v. Internal iliac veins.

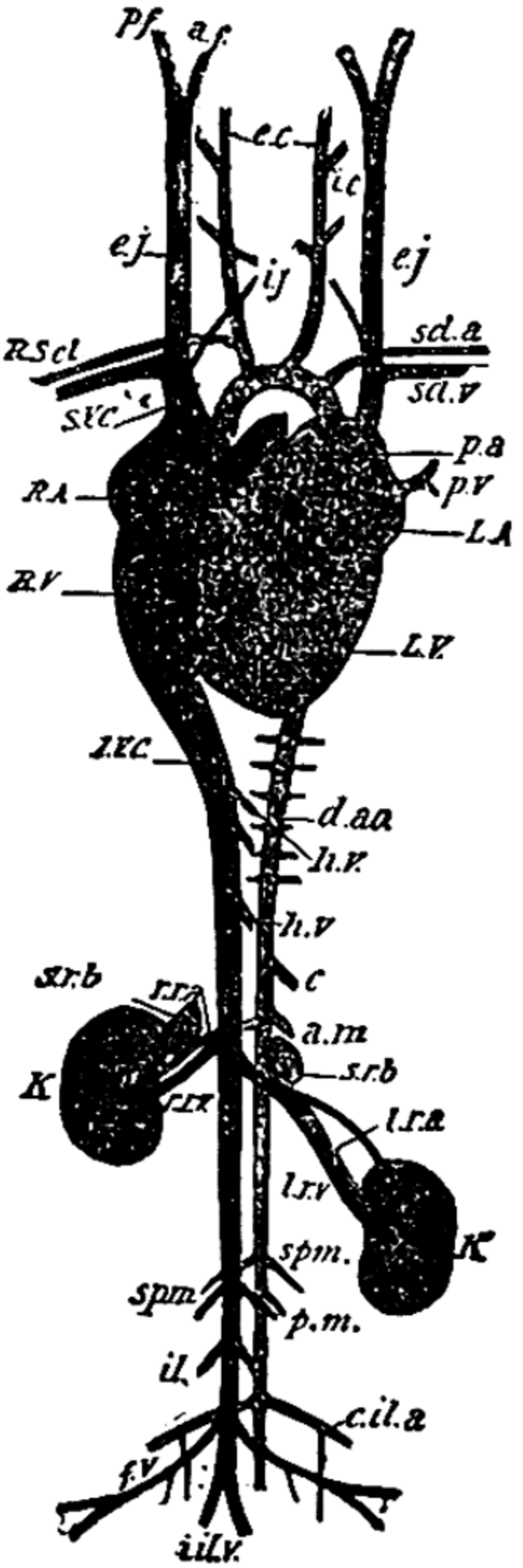


FIG. 91. The actual course of the chief arteries and veins of the rabbit

COURSE OF DOUBLE CIRCULATION.

(*A*) *Pulmonary circulation.* Right ventricle → pulmonary arteries → lung capillaries → pulmonary veins → left auricle.

(*B*) *Systemic circulation.* Left ventricle → aorta → arteries of body → capillaries of the tissues → smaller veins → vena cavas → right auricle.

In the course of one complete circuit a drop of blood passes through the heart twice, once through the right side and once through the left.

THE MAMMALIAN HEART.

Exercises

Obtain a sheep's or bullock's heart from the butcher. Ask him to leave the 'tubes' (blood-vessels) cut long if possible. Identify the apex of the heart, likewise the base where the vessels enter and leave. Notice the groove which runs obliquely down the front of the heart and separates the right ventricle, which is rather soft and flabby, from the left ventricle, which, owing to the thickness of its muscular walls, is hard and firm. This ventricle forms the apex of the heart.

Round the top of the ventricles is a circular groove which marks the division between ventricles and auricles. The auricles themselves are quite thin-walled. Make sketches of the heart which illustrate the features described above.

Identify the roots of the great veins which enter the right auricle. There are two in the sheep, an inferior and *one* superior (anterior) vena cava. Notice how thin and collapsed are the walls of these veins. Insert scissors into the anterior vena cava and slit up the vein and the auricle. Wash out the heart, then open it widely and notice the flaps (there are three) of the tricuspid valve, a structure which closes the opening between the right auricle and ventricle and prevents regurgitation (backward flow) of the blood when the ventricle contracts. Try to find out how this valve acts.

Next find and identify the pulmonary artery issuing from the right ventricle. Cut it off near the heart and, looking into it, identify the flaps of the semi-lunar valve, which guard the exit from the ventricle. This valve, which consists of three pocket-like structures, also prevents any backward flow of the blood. Insert scissors into this artery and open up the right ventricle. Notice exactly what is meant by the statement:

(1) That the pulmonary artery leaves the heart at its front (anterior) end.

(2) That the blood therefore pursues a somewhat U-shaped course within the heart.

Having completed the examination of the right side of the heart, examine the left side in the same manner. Identify the two short pulmonary veins which, in the sheep, enter the left auricle. In the rabbit there are also two, but in man there are four, two from each lung.

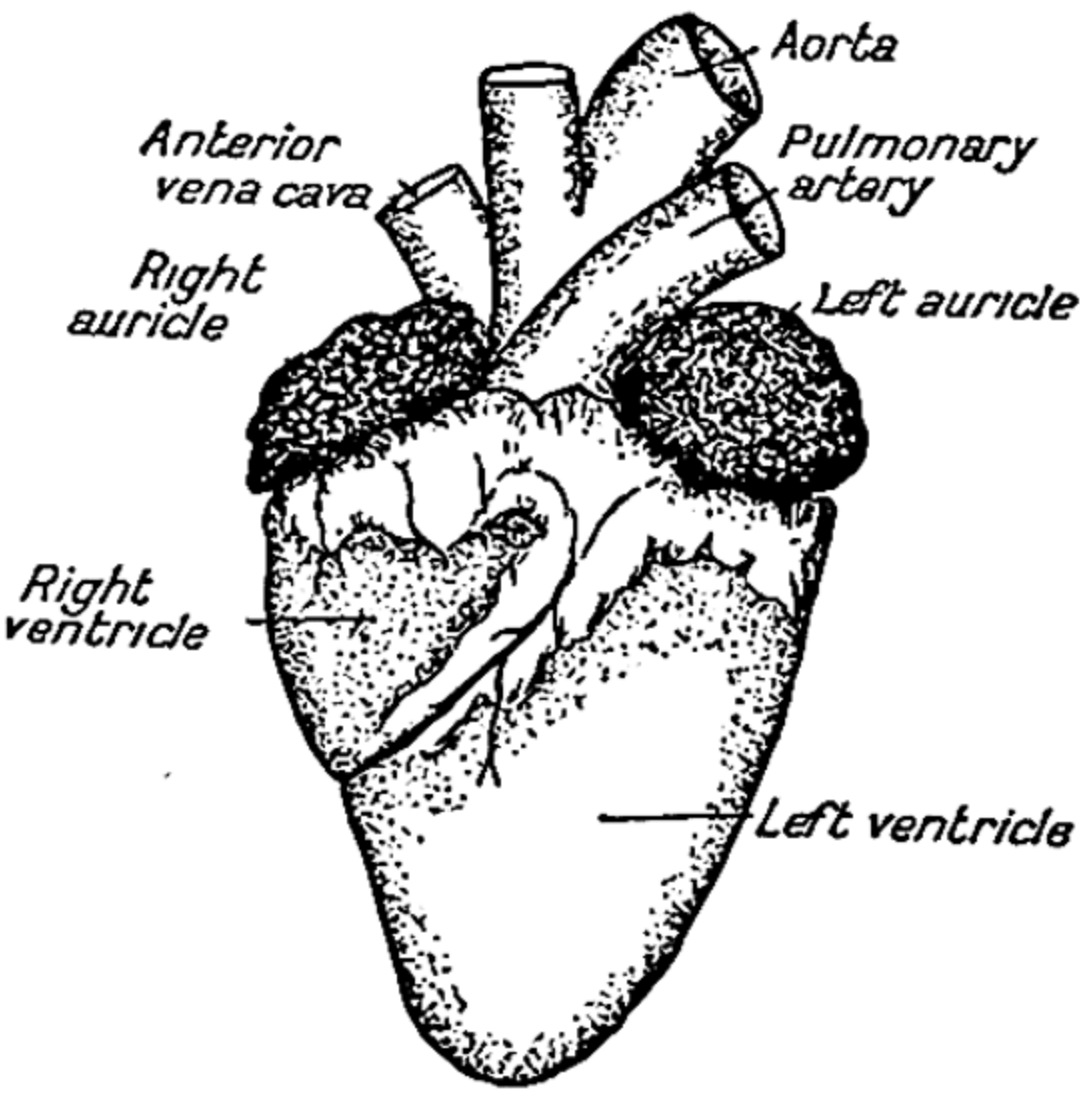


FIG. 92. Heart of sheep from ventral side

Open the left auricle widely, in order to see the two flaps of the mitral valve, guarding the orifice between auricle and ventricle. Identify the aorta and notice its thick muscular wall. Cut the aorta across close to the heart and find the three semi-lunar valves, like those already seen at the entrance to the pulmonary artery. Insert a length of glass rod into the aorta, and notice that it passes into the ventricle. Slit up the aorta and the ventricle, and observe the great thickness of the latter's muscular walls. Remember that this ventricle drives blood all over the body.

Examine the rabbit's heart in a similar manner and make drawings to illustrate its structure.

ACTION OF THE HEART. The heart walls are formed of a special kind of muscle which possesses great power of contraction. A piece of heart muscle, kept supplied with oxygen and nutrient material, will continue to beat even when completely isolated from the body. All through life the heart beats rhythmically, that of an adult man contracting about 70 times a minute, of a woman somewhat more rapidly, of a child more quickly still; it never rests except between the beats. The whole organ is not contracting simultaneously; in the mammalian heart each contraction starts in the tissue forming the junction between the vena cavas and the auricles. The contraction then grips the auricles and they contract together; this is followed immediately by the contraction of the two ventricles. Then there is a pause during which the muscle rests while the auricles are being again filled up from the veins. The cycle then recommences. The heart is more accurate in its action than the finest watch, and more powerful, in proportion to its size, than a steam-engine.

ARTERIES, VEINS, CAPILLARIES. The vessels in which the blood flows are of three kinds—arteries, capillaries, veins. The arteries convey the blood at high pressure from the heart to the capillaries. To withstand this pressure they have thick walls which contain large numbers of fibres, both muscular and elastic. With each beat of the heart the pressure in the arteries is suddenly raised and their elastic walls give a little. Hence, when we put our finger on an artery, we feel a slight expansion with each beat. This is called the pulse.

From the large arteries the blood passes into smaller ones and thence to the capillaries (cp. Fig. 95). These are so fine that they are invisible except with the microscope, the bore often being just large enough to allow the red blood-corpuscles to pass along them in single file, while the walls are as thin as the skin of a soap bubble. It is through the walls of these capillaries that all exchanges between the blood and the tissue cells occur. For example, oxygen, sugar, &c., which are required for respiration, pass into the cells, while carbon dioxide and other waste products pass out into the blood. This exchange is the work of the *lymph*, a part of the blood which can escape

through the walls of the capillaries and which bathes the cells (cp. p. 309).

From the capillaries the blood at low pressure is collected up into the veins. These have thinner walls than the corresponding arteries and are larger, as blood is passing through them more slowly. All the larger veins have valves set at intervals along their length which allow the blood to flow only towards the heart. These valves are pocket-like structures, resembling the semi-lunar valves found where the great blood-vessels leave the heart.

In a few cases blood may pass through two sets of capillaries before going back to the heart; any such arrangement is called a portal system. The vein bringing blood from the capillaries of the alimentary canal, for example, passes in all vertebrate animals into the liver, where it breaks up into another set of capillaries before the blood finally flows through the hepatic veins into the general circulation (cp. Figs. 85, 90, 100). This arrangement allows the substances absorbed from the intestine into the blood-stream to be given up again to the liver cells. In the frog there is a second portal system connected with the kidneys (cp. Fig. 100).

THE DISCOVERY OF THE CIRCULATION OF THE BLOOD. It will be remembered (cp. p. 14) that it was WILLIAM HARVEY, a famous Englishman, court physician to King Charles I, who first showed definitely that there is a true closed circulation in the blood-vessels of animals. Harvey tells us how he

'began to think whether there might not be a motion, as it were, in a circle, . . . this I afterwards found to be true.'

He worked out the course of the circulation, as given above, and described it in his book *De Motu Cordis et Sanguinis in Animalibus*, which was first published in 1628. An excellent account of Harvey's work will be found in *The Discovery of the Circulation of the Blood*, by C. Singer (cp. p. 17), a book the student is strongly advised to read. Harvey proved that there is a continuous circulation in the blood-vessels of the higher animals; in our own bodies about nine pints of fluid are thus kept in continuous motion.

THE SUPPLY OF OXYGEN TO THE TISSUE CELLS OF A MAMMAL. We have now studied two aspects of the oxygen-supplying mechanism in a mammal:

(1) The lungs, organs for facilitating the gaseous exchanges necessary for respiration.

(2) The circulatory system, by which oxygen is carried to every cell of the body.

We turn now to

(3) The breathing mechanism; by movements of inhalation and exhalation the air in the air-spaces of the lungs is constantly changed.

RESPIRATORY MOVEMENTS IN A MAMMAL. In the mammal the trunk is divided into chest (or thorax) and abdomen (cp. Figs. 3, 4); the heart and lungs lie in the chest cavity, the walls of which are strengthened by the backbone, ribs, and breast-bone (sternum) (cp. Figs. 93, 131). The floor is formed by the muscular diaphragm, which is not flat, but arched forwards (upwards in man) into the chest cavity. The lungs lie freely suspended in this airtight cavity, being only attached by their roots (cp. Figs. 3, 4).

Exercises

You should examine a dissection of a rabbit in which the thorax, lungs, and diaphragm are displayed, so that you may realize the relative position of these structures. Examine also a mounted skeleton of the rabbit and recognize the bony framework of the thorax.

Observe your own breathing movements and those of your fellow pupils. Notice particularly the raising of the chest wall and the movements of the abdomen.

Air is introduced into the lungs by enlargement of the chest cavity. This is brought about by the downward movement of the diaphragm and the elevation of the ribs. This causes an inspiration, for the pressure of the air within the lungs decreases as their volume increases[1] and air enters through the nostrils until this internal pressure becomes equal to that of the atmosphere. The lowering of the diaphragm causes an increase of pressure in the abdomen, whose walls relax. These

[1] The reader is probably familiar with that very fundamental gas law expressed by the equation PV = a Constant at any one temperature.

walls then contract and drive the now relaxed diaphragm back into the arched position. The whole action resembles that of a pair of bellows; expand the cavity of the bellows and air enters; contract it and air is expelled through the nozzle. The exact action is made clearer by the following experiment.

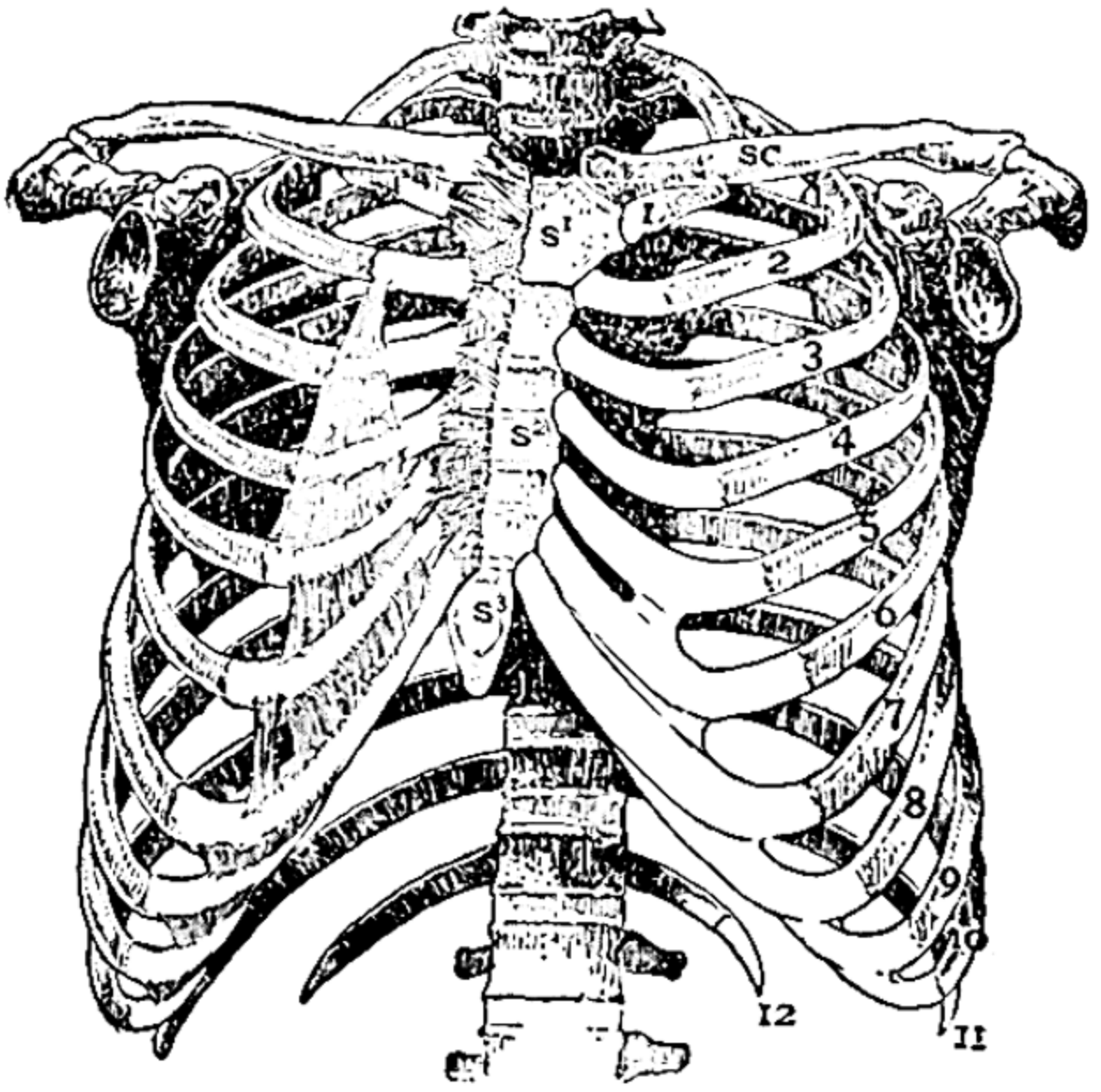


FIG. 93. THE BONY THORAX IN MAN. 1–12, ribs; s^1, s^2, s^3, sternum; *sc*, the clavicle or collar-bone; behind, the thoracic portion of the spinal column (12 vertebrae) and the first two lumbar vertebrae. Observe the socket for the arm and the scapulas or shoulder-blades (behind the ribs)

Experiment 97. To make a model which will illustrate the effect of enlarging the thorax on the air-content of the lung we take a large bell jar (this will represent the thorax). Close the narrow end (this will represent the neck) with a tight-fitting one-holed cork. Then take a toy balloon (to represent the lungs) and bind it to the end of a glass tube (to represent trachea, glottis, and nasal air-passages). Push the other end of the tube through the hole in the cork and adjust its length so that the balloon hangs freely in the cavity of the bell jar. If we close the open end of the jar by binding over it some thin sheet

rubber (to represent the diaphragm) the model is ready for use. As we depress the sheet of rubber air enters the balloon; as we push it up the balloon empties.

FUNCTIONS OF THE NOSE. One last feature of the mammalian breathing apparatus remains to be described. This is the long passage which leads from each nostril into the throat (cf. Fig. 4). The air is warmed, cleaned, and moistened as it passes along this passage, and is thus prepared for entering the lungs. When these functions of the nose are realized, the folly of 'mouth breathing', a bad habit in which many people indulge, becomes obvious.

Exercise. Examine the skull of a rabbit, dog, or sheep; identify the hard palate, and notice the length and structure of the nasal passages and likewise the bones which project into them.

BLOOD AND ITS FUNCTIONS. In our study of respiratory mechanisms we have constantly referred to a circulating fluid. All the higher animals possess a blood-vascular system; it is as necessary to them as is an efficient transport system to the life of a modern town. This fluid is not only the distributor of oxygen and the remover of the carbon dioxide formed by tissue respiration; it distributes all the substances which the cells require, and removes, quickly and efficiently, all the waste products resulting from the cell's activities.

The blood also performs some of the functions of a postal system and of a police system. It distributes certain chemical substances known as *hormones* which co-ordinate the activities of the various parts of the body (cp. p. 225). It plays an important part in defending the body against disease. In warm-blooded animals it distributes the heat evenly over the body and so helps to regulate the body's temperature (cp. p. 340).

Blood is a fluid tissue consisting of a watery solution called the plasma, in which float certain living cells called corpuscles (cp. p. 308). Further, it contains a pigment which has an affinity for oxygen, haemoglobin being the commonest of these respiratory substances. 100 c.c. of human blood will take up 15·5 c.c. of oxygen, while 100 c.c. of water will only absorb

0·7 c.c. The advantages of such a fluid as a carrier of oxygen to deep-seated tissues are obvious. The respiratory pigment is sometimes dissolved in the blood-plasma, as in the earthworm. In vertebrate animals the haemoglobin is always contained in definite cells, the red corpuscles.

VERTEBRATE BLOOD. Let us first examine our own blood under the microscope.

Exercises

Have ready a clean glass slide and clean cover-slip. Bind up your first finger tightly, starting at the root and working towards the tip,

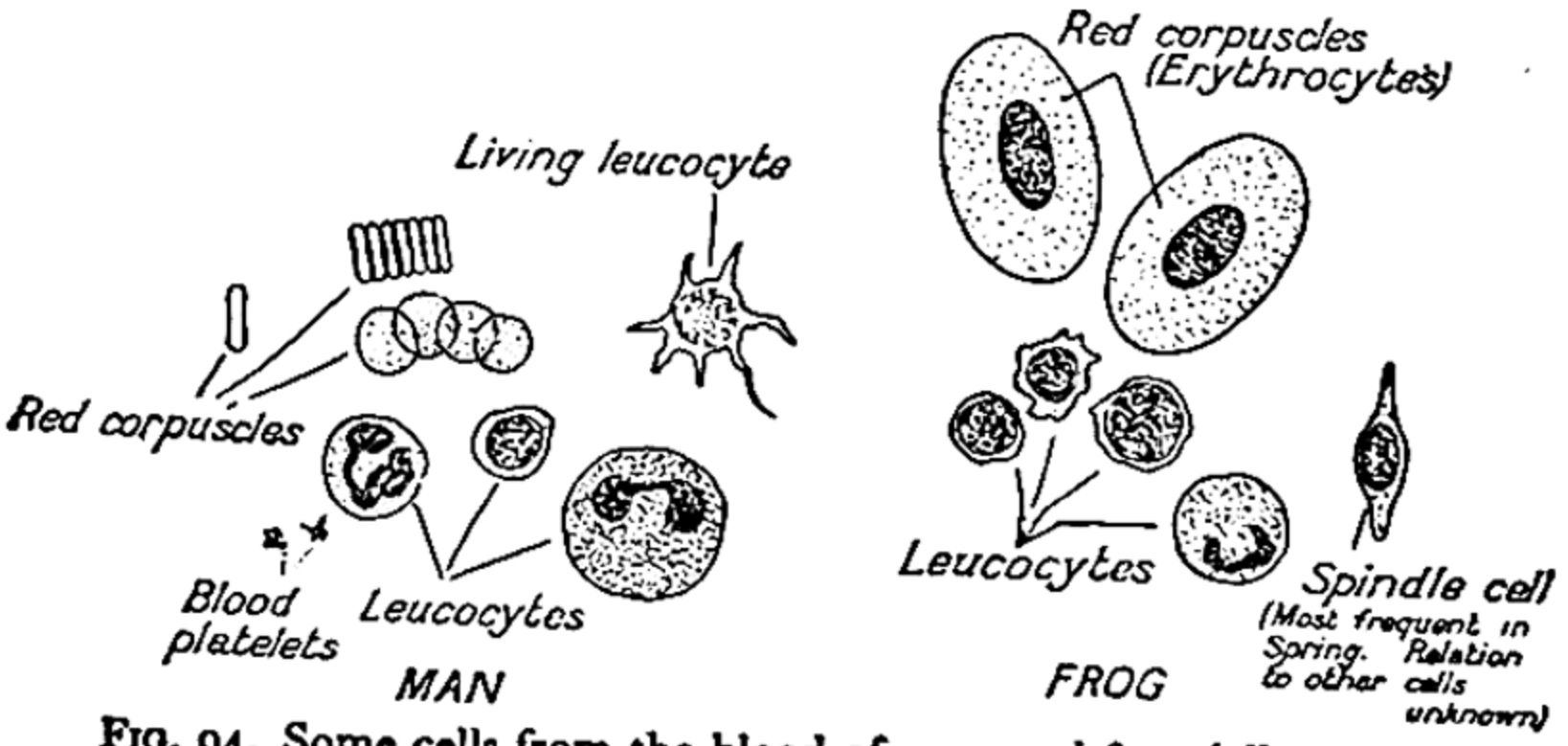


FIG. 94. Some cells from the blood of man and frog (all × 700)

so as to make blood collect in the last joint, which is left exposed. Sterilize a sharp needle by passing it through a flame, and use it to prick the finger near the tip. A sharp jab is better than a gentle push and need cause no pain. Let the drop of blood which exudes fall on the slide, cover immediately, and examine under the microscope. You will notice large numbers of round, flattened, yellowish cells, devoid of nuclei; in human blood they tend to run together into groups, like piles of coins. These are the red corpuscles. Here and there among them are amoeboid white corpuscles (leucocytes). To see these at their best a drop of blood is rapidly mounted on a warm slide. It is then possible to see that these cells are truly amoeboid; you may even be able to observe the extrusion of irregular processes (pseudopodia).

Examine a drop of fresh frog's blood in the same way. Notice that the red corpuscles are nucleated and oval, and that they do not tend to run together. Look for the white corpuscles.

We see that the blood of vertebrates consists of the plasma and of two types of corpuscle, red and white. Plasma is a straw-coloured fluid, consisting of 90 per cent. water with proteins, salts, &c., dissolved in it.

The red corpuscles are rounded or oval nucleated cells (except in the mammal, where they do not possess nuclei). The red pigment which they contain (cp. p. 282) readily takes up oxygen, and is thereby transformed to oxyhaemoglobin, a bright-red substance which is a loose chemical compound of haemoglobin and oxygen. This change takes place in the capillaries of the breathing organ (skin, gill, lung, &c.). The oxyhaemoglobin becomes haemoglobin once more, a purplish pigment, in the tissues to which it gives up its oxygen.

The white corpuscles (*leucocytes*), of which there are several types (cp. Fig. 94), are amoeboid cells, capable of multiplication by division, and endowed with power of movement. They are the scavengers of the body; the ability to change their shape enables them to squeeze through narrow spaces, and if tissue cells are destroyed by injury, &c., as in a wound, these corpuscles literally eat up (ingest) the dead cells. Many of the leucocytes can ingest solid bodies such as bacteria; because of this power they help to rid the blood of foreign matter and hence form one of the best defences of the body against disease. Such cells are known as phagocytes (warrior cells).

THE FLOW OF BLOOD. Very good cinematograph films are in existence which bring vividly before the eye the flow of the blood-plasma and corpuscles through fine capillaries, such as those which we find in the web of a frog's foot or in the tail of a tadpole.

'In the smallest capillaries, so narrow and tortuous is the passage that the red corpuscles march in single file. They move in the centre of the stream where the current is swiftest. To the outside moves a layer of transparent plasma; in this a white corpuscle is occasionally to be seen rolling along, sticking now and again to the wall of the blood vessel.'

One of these films should be seen if possible. Failing this, we may examine the circulation in the tail of a living tadpole.

Exercise. Wrap up a young tadpole very carefully in moist blotting-paper, leaving the tip of the tail exposed. The animal keeps still and may be placed on a glass slide, when we can examine the tip of its tail under the microscope. If the blotting-paper is kept moist the animal suffers no harm and the circulation of the blood in the fine capillaries of the tail can be observed.

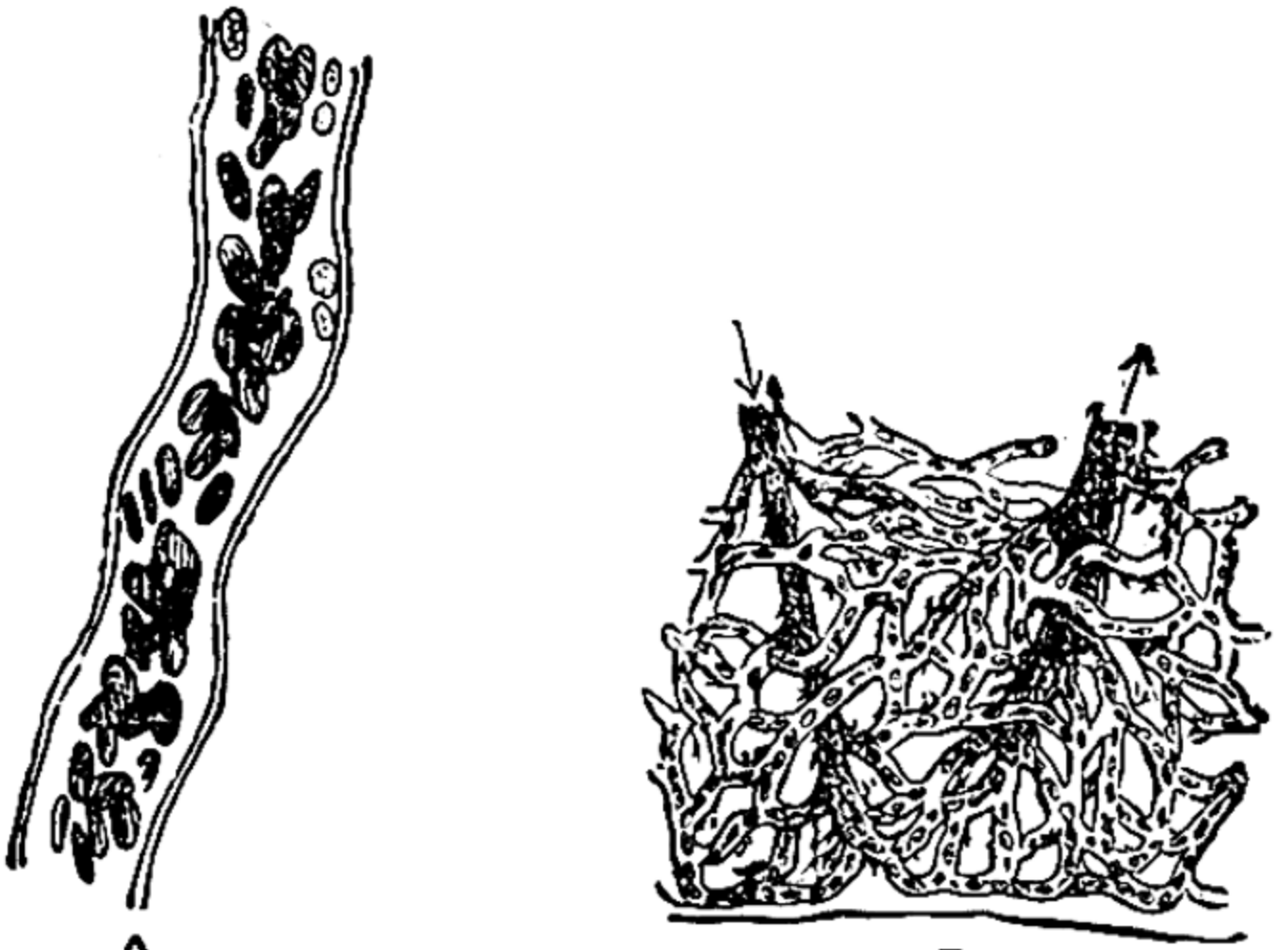


FIG. 95. **A.** A capillary vessel showing the flow of the blood-corpuscles through it (after Allen Thomson). **B.** A network of capillaries, as seen with the low power of the microscope, in the web of the frog's foot. Observe the small arteriole (left) and venule (right) which connect them

LYMPH AND THE LYMPHATIC SYSTEM. The lymph is a colourless fluid (blood-plasma) containing white corpuscles, which exudes from the blood-capillaries and bathes the tissues; exchanges between the blood and the body cells take place largely by its agency (cp. p. 286). This lymph, carrying with it the waste products of cell metabolism, is collected again into a series of extremely thin-walled vessels, known as lymph-capillaries. These unite to form larger lymph-vessels. The lacteals of the small intestine (cp. Fig. 41 B), into which digested fat is absorbed, form a part of the same system; so do certain

larger lymph spaces found scattered through the body (e.g. those between the skin and the body wall of a frog).

Lymphatic glands, in which new white corpuscles are formed, occur at intervals along the course of the lymph vessels (some of which are contractile). Finally, the lymph is returned into the general circulation. In mammals the largest vessel bringing it back is the thoracic duct, which opens into one of the large veins of the neck.

In the frog there are two pairs of small pulsating vessels which enter the circulatory system; one pair opens into the subscapular veins, the other into veins returning from the legs. So the lymph is in every case returned into the general circulation. The whole lymphatic system is an adjunct of the blood-vascular system.

QUESTIONS ON CHAPTER XXIV

For questions on this chapter see the questions to Chapter XXV.

CHAPTER XXV

BREATHING MECHANISMS IN ANIMALS

III. SOME SEMI-AQUATIC ANIMALS

AIR-BREATHING ANIMALS WHICH CAN LIVE IN WATER. In examining the respiratory systems of animals we have studied some creatures that are wholly aquatic, others that are wholly terrestrial. Certain forms do not belong to either of these groups. There are first of all a few terrestrial air-breathers which live under water; familiar examples are whales, porpoises, and seals among mammals, marine turtles among reptiles, gnats and water-spiders among invertebrates. These all inhale air, and usually they must come to the surface to renew their supply. Some air-breathers, however, have solved the problem of remaining permanently under water. Let us examine a few of these forms.

THE WATER-SPIDER. Spiders are land animals belonging to the arthropod group, and usually have tracheae or air-tubes for respiration just as insects have (cp. p. 291). In addition many have 'lung books' consisting of very thin, hollow plates of tissue, well supplied with blood, which project into an internal cavity where an exchange of gases can occur.

Hence the typical spider is purely terrestrial, yet water-spiders have taken to an entirely aquatic existence, spending their whole life beneath the surface of ponds and sluggish streams. Nevertheless, they inhale air; each spider builds for itself a dome-shaped web under the surface of the water, which it skilfully attaches to some suitable water-plant. By diving down continually, carrying with it a bubble of air entangled in the hairs of its abdomen, the little creature fills its under-water 'tent' with air, and so lives remote from terrestrial enemies, absorbing the trapped air into its breathing organ.

This web is often called a nest because in late summer the female spider deposits her eggs in it, separating off the upper portion of the 'nest' by a wall of silk; in this nursery she lays her eggs and rears her young (cp. p. 495).

Exercises

Examine and draw a spider and notice the external features of these animals.

Water-spiders are easily kept for a time in an aquarium; you should try to catch some and supply them with water-weed, when they will construct their wonderful 'tents' for you before your eyes.

GNATS AND MOSQUITOES. Gnats and mosquitoes are members of the fly family, one of the many subdivisions of the insect group (cp. p. 460). Although aerial creatures, they lay their eggs on water, and their life-histories are full of interest. In that of the common grey gnat we may observe the following stages:

(1) The eggs are laid in floating 'rafts' on the surface of stagnant water.

(2) These eggs float on the surface and in a few hours the larva emerges, head downwards. The larvae live immersed in water, yet they use air for respiration. They absorb this air through a tube (tail-trumpet) (cp. Fig. 96). They rest at the surface of the water, the tail-tube being kept just above the surface like the periscope of a submarine.

(3) In about ten days and after casting its skin several times, the size increasing after each moult, the larva is full-grown. On the eleventh day it changes into a pupa, which floats head uppermost and obtains air for respiration by two spiracular openings (cp. Fig. 96).

(4) On the fourteenth day the pupal skin is split and the winged insect emerges. Resting on its empty case it spreads its wings, and very soon it flies away into the air, where the remainder of its life will be spent.

Exercise. Examine and sketch both larvae and adult insects of some common British gnat. Observe carefully the structure of the mature insect, and compare it with the general account of insect structure given on p. 157.

Eventually the female insect (gnat or mosquito) lays a raft of eggs and the story begins once more. All these creatures have a similar life-cycle, with a larva which lives in water and an adult which is terrestrial. Yet these animals are never truly

aquatic; all through their larval life they must come to the surface to absorb air.

MOSQUITOES AND MALARIA. The adult female insects of both gnats and mosquitoes are blood-sucking parasites, while the

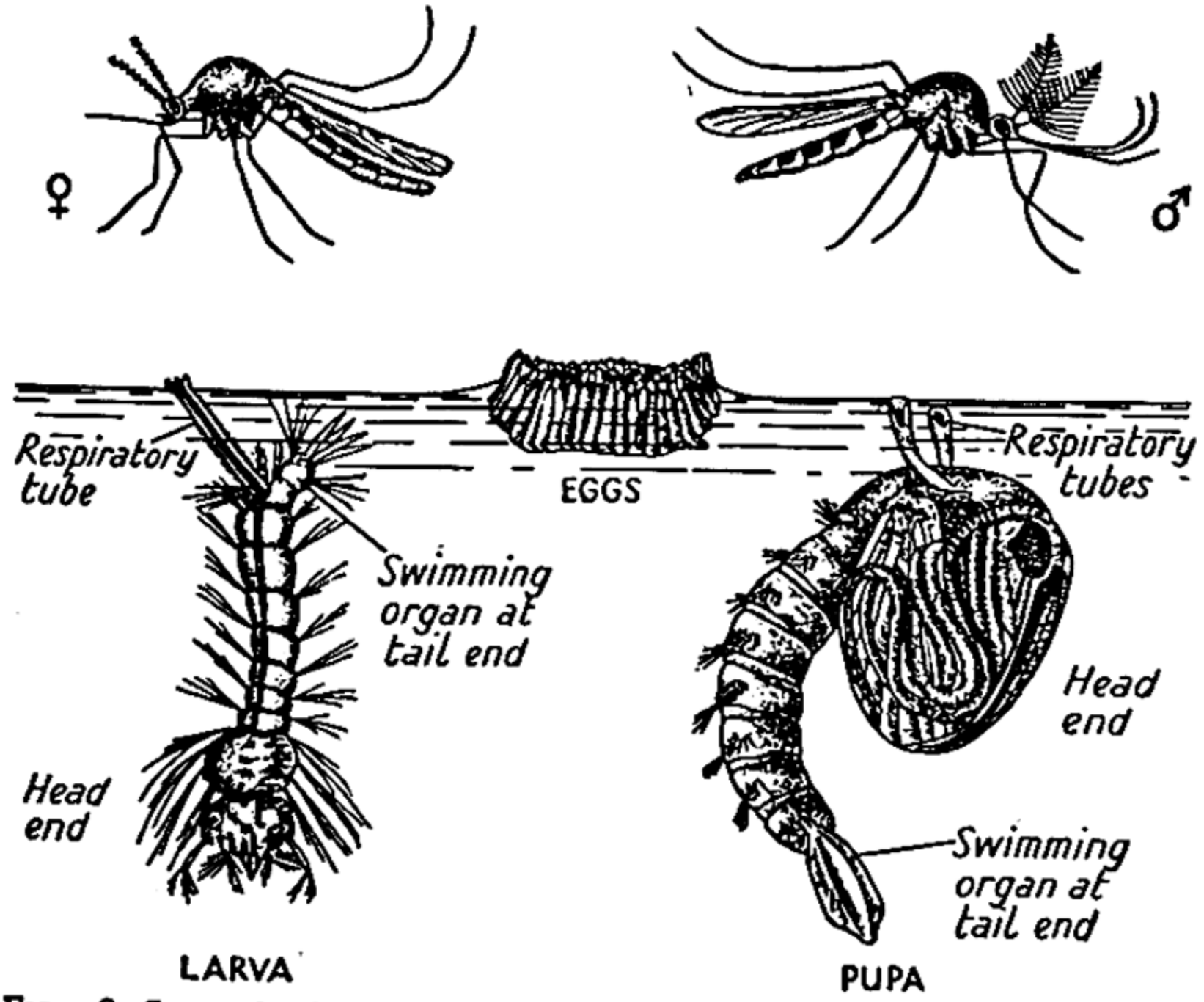


FIG. 96. Stages in the life-history of the gnat (Culex). Above, the mature insects (male and female)

males live comparatively harmless lives sipping the nectar of flowers. Towards the end of last century it was proved that malaria is carried from one human subject to another by certain mosquitoes. The story of this epoch-making discovery is told more fully on p. 205.

WATER-BREATHING ANIMALS WHICH CAN LIVE FOR A TIME IN AIR may be contrasted with those just described.

Eels are true fishes breathing by gills. Examine one, if you can. Yet, unlike most fishes, they can live for hours out of water, and can slither and slide over damp grass for many

miles on their long journeys to and from the sea. The story of these journeys is told on p. 396. Climbing perch likewise can leave the water for long spells and move about on land in search of insects. These fish have gills, but the whole apparatus is so formed that, in addition to being used for absorbing oxygen from water, certain of the membranes adjacent to the gills can, at need, constitute an efficient air-breathing organ.

Most bony fishes have an organ called the swim-bladder, an outgrowth of the gut whose chief function is probably hydrostatic, i.e. it helps the fish to adjust its total volume so that it can maintain its level in the water.[1] In the lung-fishes (also called mud-fishes) of certain tropical rivers this swim-bladder is two-lobed, large, and sponge-like, and can be used as a true lung. These fishes have degenerate, often almost functionless gills. Even when immersed in water they frequently rise to the surface and fill the swim-bladder, which opens into the gut, with air. If the river level falls, as in times of drought, they depend entirely on this air for oxygen. They burrow into the soil and remain there dormant, encased in damp mud, for many months.

'These capsules, with the surrounding earth, have often been transported from Africa (one genus of lung-fish lives in the Gambia and certain other African rivers) to Northern Europe without injury to the dormant life within.

'Specimens have sometimes come out alright, even after they have been out of the water for nine months. A fish out of water indeed!' (*The Haunts of Life*. Thomson.)

The swim-bladder of the typical fish has, in these strange forms, assumed all the functions of a lung, and hence these creatures are largely independent of the water which must have been their ancestral medium. The swim-bladder is here seen as the forerunner of the lung (cp. p. 516).

[1] When the swim-bladder is filled with gas the total volume of the animal increases, and vice versa. When its volume increases the fish displaces more water for the same weight and so becomes more buoyant (Principle of Archimedes).

ANIMALS WHOSE EARLY LIVES ARE SPENT IN WATER, THEIR ADULT LIVES ON LAND. This group, which is perhaps the most interesting of all, includes many animals which only become transformed to air-breathers as they reach maturity. The dragon-fly and the frog are examples of this way of life among the familiar creatures of the English country-side.

THE DRAGON-FLY

These insects are often seen on a sunny summer's day, flitting about near ponds and streams. But let one small cloud obscure the sun and they vanish immediately; children of the sun, they subside into lethargy when it is not shining.

Exercise. Examine and draw an adult insect; its body is divided into three distinct regions—head, thorax, and abdomen. Notice the head, large in proportion to the body, which has two prominent compound eyes, three simple eyes (ocelli), and two short antennae. The thorax consists of three segments, each of which bears a pair of jointed legs. Dorsally, attached to the two hinder segments are the two pairs of wings. These wings are very characteristic, being thin and transparent, often highly polished, glistening, and beautifully coloured. The abdomen is long, thin, and segmented. Try to determine the number of segments. Try also to find the spiracles.

THE LIFE-HISTORY. This insect, like nearly all its kind, undergoes *metamorphosis* or a complete change of form in the course of its development, and its life-history can be summarized as follows:

Larval stages.

1. The eggs are laid on water, often on or in the tissues of water plants.
2. Some weeks later a minute helpless pronymph emerges from each egg.
3. This at once splits its skin (cp. pp. 392, 403) and discards it. A small active nymph is formed.
4. The nymphs grow, shed their skins, grow, moult again, and so on for nearly a year. They are dun-coloured or greenish creatures, lethargic except when engaged in chasing food. They live at the bottom of ponds and streams, are flesh-

eaters and very voracious, living on water-fleas, worms, tadpoles, insect larvae, small insects, and the like. These nymphs or larvae are true aquatic water-breathers. They possess tracheae, as do all insects (cp. p. 291), but their spiracles are closed and air cannot enter the tracheae directly. The oxygen which it requires enters the animal's body dissolved in water. In some forms this water is sucked in and out of a sac-like enlargement at the hinder end of the gut, the entrance to this sac being protected by fine projecting bristles which prevent solid particles from entering. Fine branches of the main air tubes are spread out over the surface of the sac, and air passes into them from the contained water.

Some species have less elaborate breathing mechanisms; they depend to a very large extent on the absorption of air through the whole surface of the body.

The adult.

The four stages which we have just described do not complete the story of the dragon-fly's development. The final stage has been pictured for us by Tennyson:

> To-day I saw the dragon-fly
> Come from the wells where he did lie.
>
> An inner impulse rent the veil
> Of his old husk: from head to tail
> Came out clear plates of sapphire mail.
>
> He dried his wings: like gauze they grew;
> Thro' crofts and pastures wet with dew
> A living flash of light he flew.

5. When the nymph is full-grown it crawls up a water-weed into the air. Here its skin dries and splits down the back, the split beginning at the head end. Through this slit the adult animal gradually emerges, working its way out by active wriggling movements (cp. Fig. 97). It is a soft, colourless, helpless-looking creature, with small, creased, and useless wings. Quickly, however, the body lengthens, the new skin dries in the sun, and the wings expand. Soon—in the course of an hour or so—the creature leaves the supporting weed and takes its first flight into the air. It is now adult. In this final

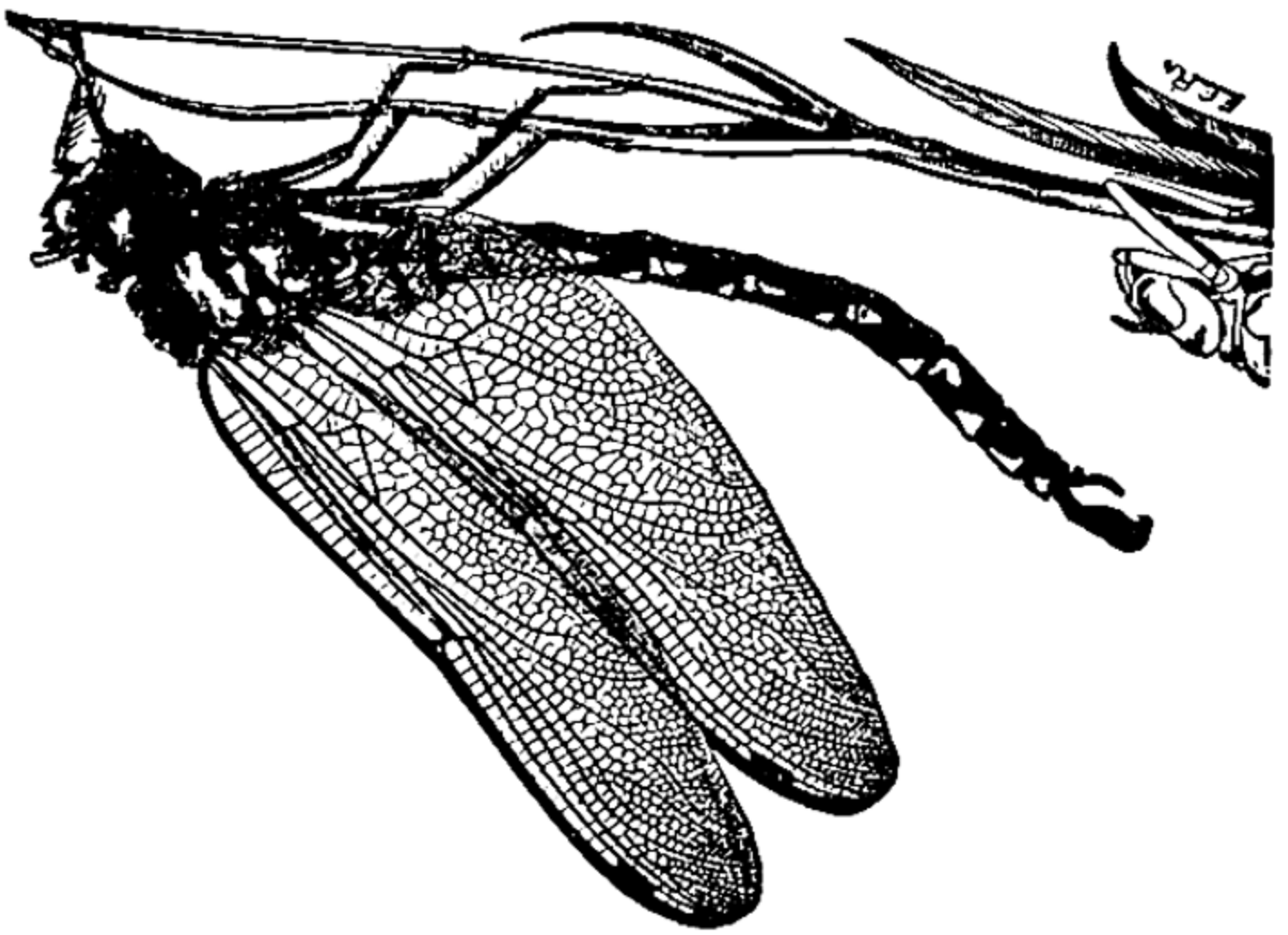


FIG. 97. THE METAMORPHOSIS IN THE DRAGON-FLY. Left, observe the skin of the larva or *nymph*. This larva is aquatic and cannot fly, otherwise it does not differ markedly from the adult. There is no resting phase (*pupa*) between larval and adult stages. When it first emerges the wings of the adult are very small but they soon become dilated by the fluid pressure of the blood.

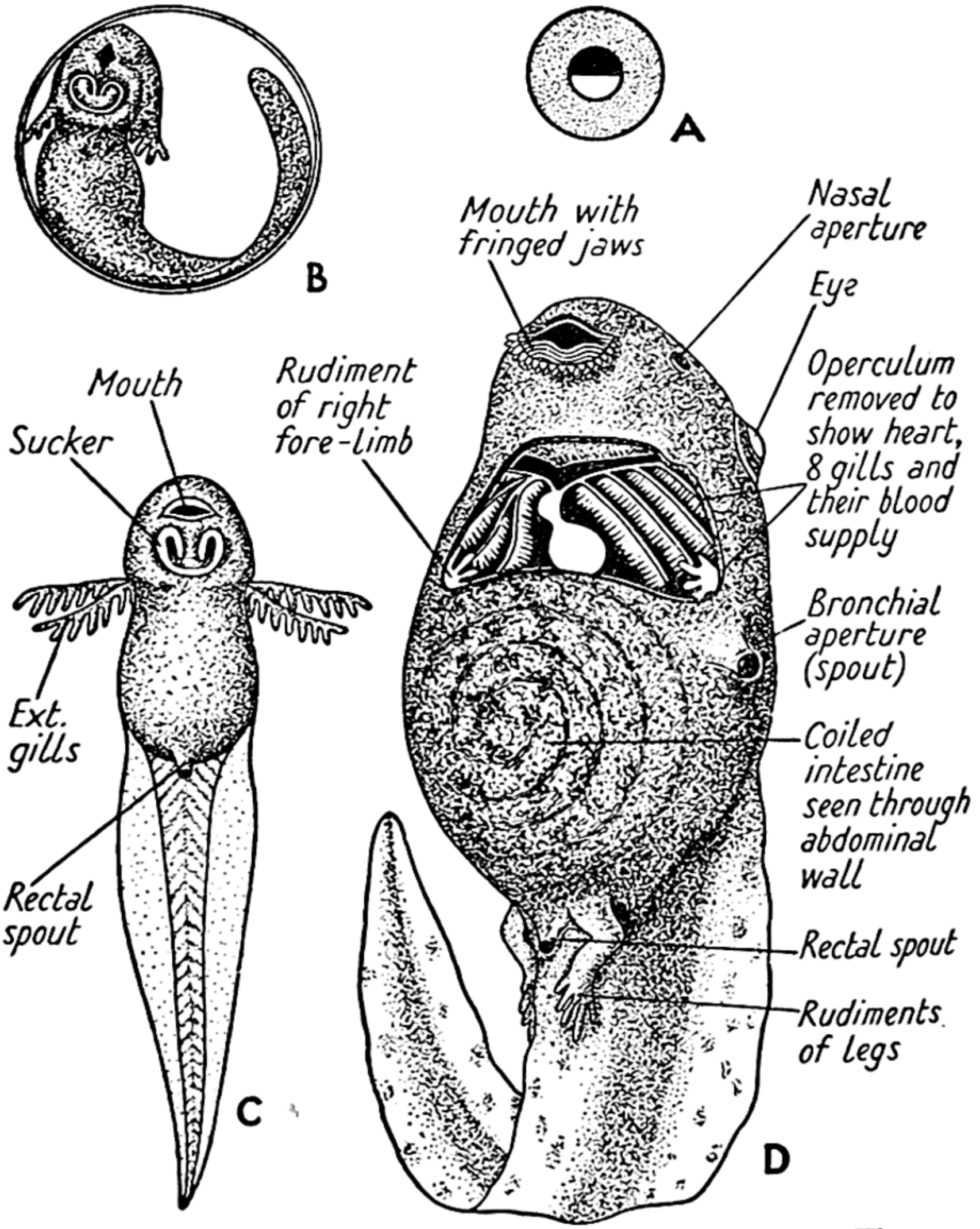


Fig. 98. Four Stages in the Development of the Frog. A. The egg. **B.** The larva ready to leave the egg jelly. **C.** The external-gill stage. **D.** The fully formed tadpole, with internal gills and a fish-like circulation. Observe the rudimentary limbs

stage of its development the dragon-fly is a truly aerial animal breathing air by means of its spiracles and tracheae (cp. p. 291).

Lantern slides can easily be obtained which illustrate this life-history and show very clearly how the dragon-fly emerges. If you seek for the opportunity you may be able to see the same thing on a film. Best of all is to do what Tennyson obviously did, to observe the facts for youself.

THE FROG

LIFE-HISTORY. This is another creature which starts life in the water to emerge finally on to the land. Every one is familiar with the masses of frog spawn which are found in spring (March and April) floating on the surface of ponds and ditches. Each black speck is a frog's egg enveloped in a gelatinous covering. The egg is a single cell with a single nucleus. The frog is a true amphibian, starting life completely adapted to living in water, but the mature animal has lungs and cannot remain in water permanently without being drowned.

Exercises

Collect frog spawn in early spring and keep some in an aquarium. This may consist of a large pudding-basin, if nothing better is available. There must be a plentiful supply of healthy water-weed, and, if the jar is small, water and weed should be frequently renewed. As the little animals develop there comes a stage when they like some animal food. A fragment of meat should then be attached to a length of cotton and lowered into the jar every morning; it may be left in position for an hour and then removed. If these instructions are followed no further attention is necessary until the creatures are preparing to leave the water; a platform of stones, &c., must then be provided.

Preserve in formalin specimens of various stages in the life-history and make drawings of them, confirming the following facts.

LARVAL STAGES. *Phase 1. The animal is dependent on food stored in the egg-cell; it has no respiratory organs and does not yet ingest food.*

1 a. The egg is half black and half white, the black half uppermost. The black begins to spread over the white until the whole egg is black. This external change marks the internal division of the egg-cell into two, four, eight, and ultimately into a mass of much smaller cells. These form a hollow sphere

(the *blastula*); later a more complex structure (the *gastrula*, cp. Fig. 125) is formed. These internal changes cannot be followed with a simple lens, but the spread of the black hemisphere over the white shows us that they are in progress. There is practically no growth, i.e. no increase in size, during this phase of development, but continued nuclear division. The result is that the protoplasm is divided up into a very much larger number of smaller units, each of these units being a nucleated cell.

1 b. Obvious growth now begins; soon the little animal elongates, head and tail begin to be marked off from the body, and it lies coiled up within the confining jelly (cp. Fig. 98 B). Internally the alimentary canal, heart and blood-vessels, brain and nervous system, excretory organs, sense organs, &c., are all being formed.

1 c. The animal, which is now beginning to look something like a tadpole, starts to wriggle within its jelly. At last, about a fortnight after the eggs were laid, it escapes and remains almost motionless, hanging on a piece of water-weed, to which it attaches itself by a horseshoe-shaped cement gland which we find on the under side of its head (cp. Fig. 98 C). This gland (or sucker) secretes a sticky adhesive slime.

At the time of hatching the tadpole has no mouth and is still dependent on the granules of stored food (yolk) which were contained in the egg-cell. A few days after hatching, gills and then mouth appear, and a new phase of its life-history has begun.

Phase 2. The external-gill stage. The animal begins to feed and possesses definite respiratory organs.

The animal now begins to move actively and to seek its own food. The gut lengthens and gradually becomes spirally coiled; digestive glands come into action. There is a head on which may be seen rudiments of eyes, nose, and mouth. Later this mouth is bordered by a pairy of horny jaws and has fringed fleshy lips (cp. Fig. 98 D); the tadpole now feeds eagerly on water-weed. It has a well-developed tail by which it swims. On the sides of its throat are three pairs of characteristic branching outgrowths; these are simple skin gills. Internally

there is a fish-like circulation (cp. p. 286), the heart driving blood through the capillaries of the gills. The animal no longer depends on an intake of oxygen through its whole surface; during this, the external-gill stage of its development, it is absorbing oxygen through its simple skin gills, as well as through its skin. It is not yet making any breathing movements.

Phase 3. The fish-like stage, with internal gills.

As growth proceeds the frilled gills disappear from the side of the tadpole's throat. Four gill-slits, rather like those of a fish, have been developed between the external gills, which connect the cavity of the pharynx with the exterior. Gill-filaments line the slits and blood begins to flow through the capillaries of these filaments. In Fig. 98 D the four arteries of each side may be observed. The external gills, having done their work, are discarded.

The animal now breathes as does a fish, inhaling water by its mouth and passing it out through the gill-slits. It swims as does a fish, although it does not possess paired fins. Its heart and circulatory system are also fish-like, the course of the blood being: tissue capillaries → veins → heart → ventral aorta → gill-capillaries → dorsal aorta → tissue capillaries (cp. Fig. 83).

These internal gill-slits are not visible on the surface of the pharynx for, very early, a fold of skin, the operculum, appears on each side of the head in front of the gills and grows down over them, fusing with the body wall below the slits, so that they are enclosed in a gill-chamber. A small aperture, the spout, remains on the left side, and through this the water inhaled during respiration escapes (cp. Fig. 98 D).

Phase 4. Metamorphosis. The animal now changes from a water-breather to an air-breather. During this phase of its existence its structure is completely altered in preparation for a very different mode of life. When the early stages of an animal are quite unlike those of the adult, the change from the larval to the adult form is called metamorphosis (cp. p. 392).

4 a. After some weeks of active life, the form of the animal is seen to change once more. The body broadens and stumps of legs become visible on each side of the tail. Toes appear,

and soon the tadpole begins to use these new organs for swimming. Front legs are formed too, but at first these are under the operculum and are not so obvious.

These external changes are accompanied by marked internal ones. The animal has developed lungs, and soon it begins to use them, coming to the surface every now and again to fill them with air. It obviously enjoys animal food. Finally its whole way of life changes.

4 b. The tadpole stops swimming about like a fish and comes more and more often to the surface to breathe. It begins to fast, and its tail is rapidly absorbed; the white corpuscles of the blood (cp. p. 307) attack the cells of which it is composed and literally devour them. The horny jaws of the round tadpole mouth are discarded, the large frilled lips shrink, and a wide frog's mouth takes their place. The gut shortens and the abdomen shrinks as the animal becomes purely carnivorous; it soon starts to eat insects, &c., even other tadpoles. The outer skin is cast off. The eyes, which were previously under the skin, are exposed and become much larger. The gill-clefts close up, and the course of the circulation changes.

The hind limbs appeared earlier as small rudiments at the root of the tail. During the seventh week their joints become visible, and about a week later toes appear. The forelimbs began to develop at about the same time, but were covered by the operculum (cp. Fig. 98 D). Now, as metamorphosis takes place, these break through this cover, the left limb pushing its way through the spout. At the same time the hind legs lengthen considerably, and the animal leaves the water.

Metamorphosis is complete; the water-inhaling, swimming, fish-like, herbivorous tadpole has become an air-breathing, leaping, tailless, carnivorous frog.

THE FULLY FORMED FROG. If frog spawn is brought into the laboratory at the end of March, this metamorphosis is usually complete before the end of June. If we have not provided a group of stones or other platform where the little creature can rest above the level of the water, it will drown when its metamorphosis is completed. It cannot remain permanently in the water. If we have kept tadpoles to this stage we shall

find the froglets sitting one day on the rocky platform. The next day, unless we take precautions, they will have disappeared, having hopped away on to the land. We must therefore now provide a new home, a cage on dry land, and

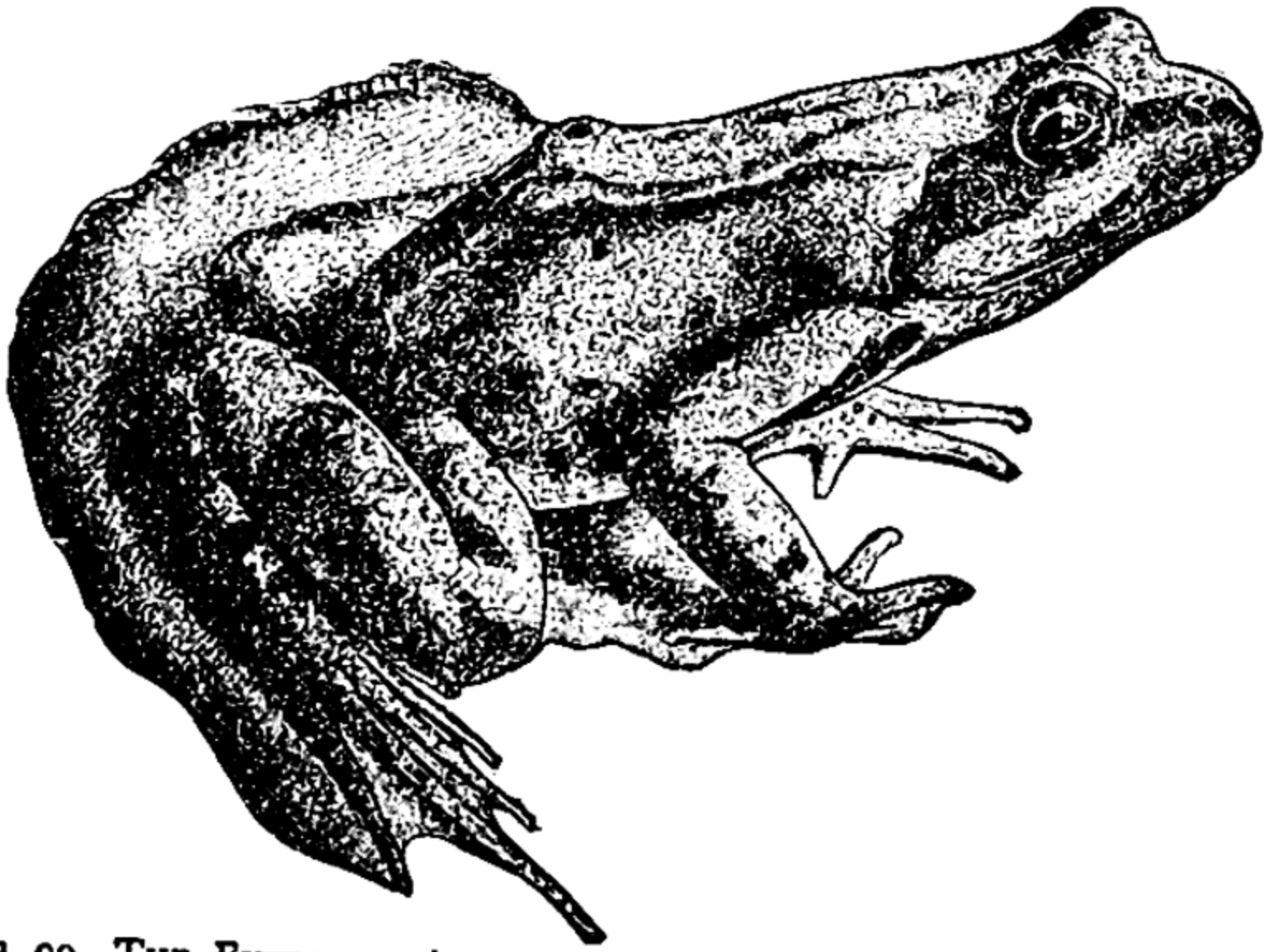


FIG. 99. THE EXTERNAL APPEARANCE OF THE FROG. Observe the large mouth, the external nares, the protruding eyes, and the tympanum (or ear-drum) visible on the head. Note the short fore-limb (arm, forearm, hand with four digits), the long hind-limb (thigh, leg, long ankle, and foot with five toes webbed together). Observe the spotted nature of the moist skin (protection coloration) and the absence of tail

a diet of insects or tiny worms. This cage should contain a little pool in which the frogs can immerse themselves at intervals.

RESPIRATION IN THE ADULT FROG. The lungs are usually the chief respiratory organs in terrestrial vertebrates, but the frog absorbs a good deal of oxygen through its skin and through the mucous membrane of its mouth. It is not fully adapted to life on land. There are secretory glands which keep the skin permanently moist and slippery; oxygen dissolves in this moisture and is absorbed. Through its skin and the thin

membrane lining the mouth the animal obtains enough oxygen to support life for some time, even if the lungs are entirely removed.

Let us now inquire how air is drawn into the mouth cavity and lung.

Exercise. Examine the head and mouth of a frog; open the mouth and examine its internal structure.

The frog has a large mouth and two nasal apertures (external nares). From each of these a small passage leads into the front of the mouth at the internal nares (cp. Fig. 43). At the back of the throat is the glottis, which opens into a short trachea; this divides into two short bronchial tubes, each of which terminates in a lung. These lungs, as we have seen (cp. Fig. 88), are simpler than those of a mammal, and far less efficient as respiratory organs.

RESPIRATORY MOVEMENTS IN THE FROG. We must distinguish between the movements for introducing air into the mouth, and those much less frequent movements by which it is passed on into the lungs.

(*a*) *Buccal respiration.* The mouth being closed and the external nares permanently open, air is sucked into and driven out of the mouth by the alternate lowering and raising of its floor. Oxygen is absorbed from this air into the capillaries in the thin mucous membrane lining the mouth cavity.

(*b*) *Lung respiration.* This only takes place at irregular intervals. The mouth, not the thorax (cp. p. 304), is the organ by whose movements air is caused to enter and leave the lungs. The frog has no thorax and no diaphragm; its ribs are represented by short outgrowths attached to each vertebra, and they in no way enclose the chest cavity. (Cp. Fig. 132.)

Exercise. Carefully watch a living frog and confirm the following facts. The taking of one breath involves the following three movements:

1st movement. The floor of the mouth is lowered, the mouth is closed, the nares open. The glottis is also closed. Air enters through the nasal passages to equalize the air pressure inside and outside the mouth.

2nd movement. The external nares are closed, the mouth remains closed, but the glottis is open; the floor of the mouth is raised by muscular contraction and air is driven into the lungs.

3rd movement. The nares are opened, the abdominal muscles contract, the elastic walls of the lungs recoil and air is expelled.

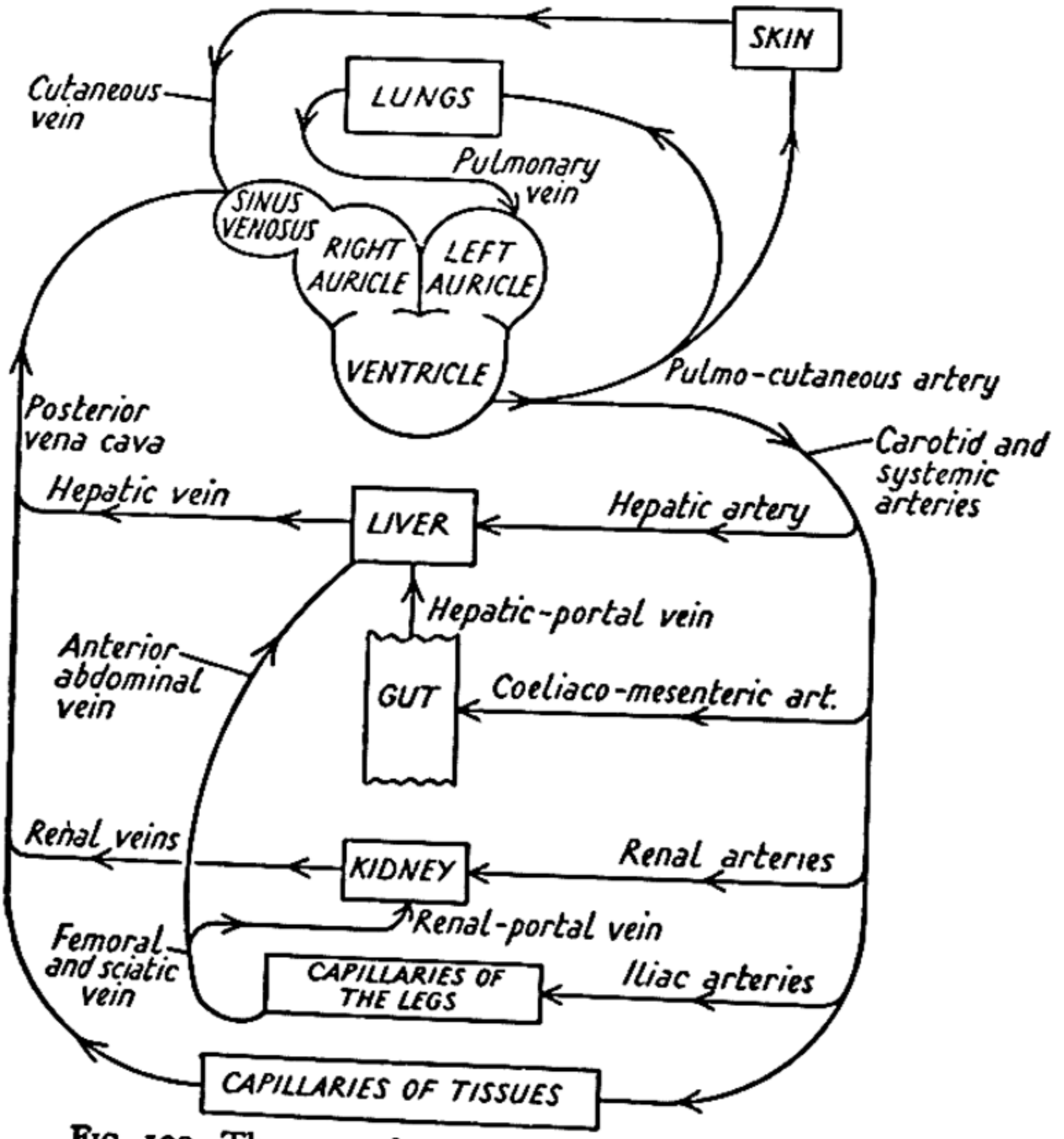


FIG. 100. The general course of the circulation in the frog

THE CIRCULATION OF THE FROG. At metamorphosis the course of the circulation, which is fish-like in the tadpole, changes so that blood no longer flows through the gills but is driven into the lungs. The general course of the circulation in the adult frog is shown above. The heart is three-chambered with two auricles and a single ventricle. Although oxygenated

blood from the lungs and deoxygenated blood from the tissues are returned to separate auricles (left and right respectively), the contents of both are emptied at the same moment into the ventricle. There is no such complete separation of the two bloods as there is in those animals which have a four-chambered heart and separate pulmonary and systemic circulations (cp. p. 297).

THE LIFE-HISTORY OF THE FROG AND ITS BEARING ON EVOLUTION. This story of the development of the frog is a very striking one. The question at once arises, why are these many changes necessary? Why, for instance, is a fish circulation elaborated only to be rearranged to suit the life of a terrestrial animal? It seems at first sight a great waste of effort. Why does not the egg grow directly into a baby frog? When we examine the early stages of other terrestrial animals we find that similar changes occur. During the development of the chicken within the egg, for example, a fish-like circulation and rudimentary gills (which never function) are formed in the embryo.

Biologists believe that these and many similar puzzles are best explained by the assumption that there has been evolution since life appeared on earth. We shall return to this subject in a later chapter (cp. p. 513).

QUESTIONS ON CHAPTERS XXI–XXV

1. State exactly what is understood by respiration. What is the importance of this process? Describe how you could prove by experiment that plants and animals respire. (L.G.S.)

2. Describe and explain clearly what happens when yeast is added to a solution of cane sugar. (Ox.L.)

3. How do living organisms, both plant and animal, obtain their energy, and how is this energy utilized and expended? (W.)

4. State clearly what you understand by work and energy. Explain fully what is meant by saying that the food consumed by an animal contains energy which is transformed in the animal's body. (Ox.L.)

5. Energy is gained and lost by all living organisms. Give an account, with definite examples, of the various ways in which plants and animals obtain the energy they require, and briefly explain how this energy is utilized by them. (C.L.)

6. What gases are normally present in the atmosphere and which of them are vitally concerned in respiration? How could you, by simple tests, (*a*) show the presence of these gases, (*b*) illustrate their part in the respiratory process? (Ox.L.)

7. Give an account of the physical and chemical properties of oxygen. What is meant by the term combustion? Where does combustion take place in living beings, and why is it of importance to them? (Ox.L.)

8. How is respiration carried out in a typical flowering plant? Describe experiments which may be performed to illustrate the nature of respiration in such a plant. (L.G.S.)

9. Every living part of a plant requires air. Why is air necessary? How do the woody twigs of a tree obtain air? (B.)

10. Describe an experiment to show the production of heat by a plant. What is the origin of the heat produced? (J.M.B.)

11. A man enters a greenhouse at noon on a summer's day and again at 10 p.m. One part of the house is filled with green plants and the other contains a mushroom bed. Explain carefully, giving your reasons, what gaseous exchanges are taking place in the greenhouse at the different times, between all three classes of living organisms present. (L.G.S.)

12. Explain how atmospheric oxygen is obtained and utilized by plants and animals. Why is it that the constituents of the atmosphere remain approximately of constant proportions? (Ox.L.)

13. What are the sources of carbon dioxide in the atmosphere, and how do you account for the fact that its amount remains practically constant? (C.W.B.)

14. Every living part of a plant requires air. Why is air necessary? Describe and compare the methods by which a green herbaceous plant and a woody twig of a tree obtain air. (J.M.B.)

15. What are the essential features of all breathing organs? Illustrate your answer by describing and comparing the breathing organs of (*a*) a water-living, (*b*) a land-living vertebrate. (C.L.)

16. What is meant by respiration in animals? Describe the respiratory organs in either a mammal or a fish. (J.M.B.)

17. What do you understand by respiration? Describe the mechanism associated therewith in a green plant and a frog respectively. (C.W.B.)

18. Describe by the aid of diagrams the respiratory system of the mammal. Explain clearly the importance of respiration in animals and plants. (L.G.S.)

19. State the composition of the atmosphere and explain the use made by plants and animals of the various gases present. (L.G.S.)

20. Give an account of the structure and action of the heart of a mammal and trace out the general course of the circulation of the blood. (L.G.S.)

21. Construct a simple diagram to show the direction of blood-flow in the blood-vessels connected with (*a*) the respiratory system, and (*b*) the digestive system of any warm-blooded animal. Explain how the direction of the blood-flow is controlled and the reason for the direction in each case. Why is it difficult to use the brain after a good meal? (L.G.S.)

22. Describe the respiratory system and the circulatory system connected with it in a fish. (C.L.)

23. With the aid of diagrams, describe the circulatory system (excluding the structure of the heart) in the frog. What are the chief functions of the blood? (O.L.)

24. Describe the structure of the heart of a frog or of a mammal. Make a drawing to show clearly the chief vessels entering and leaving each of the chambers and state from what organs the different vessels come and the difference of the composition of the blood in each of them. (C.L.)

25. Write an essay on the importance of the blood-vascular system, not omitting reference to its absence in lower forms. (C.W.B.)

26. How is respiration carried out in the fish and the frog respectively? Illustrate your answer as far as possible by diagrams. (C.L.)

27. Omitting microscopic details, describe the respiratory system of a fish and of either a bird or a mammal. What respiratory movements occur in the types you select? (J.M.B.)

28. Describe the structure and mode of action of the respiratory system of the cockroach or grasshopper. What are the functions of the blood in the type you select? (J.M.B.)

29. Describe the structures through which gases enter and leave the various parts of a tree. How is this interchange of gases checked when the tree becomes dormant in winter? (J.M.B.)

30. In what ways are conditions (*a*) favourable, and (*b*) unfavourable, for flowering plants living in water? Select any *two* such water-plants and explain how the structure and life-history of each is adapted to its condition of life. (J.M.B.)

31. Describe the chief external characters of any fish with which you are familiar and give an account of its mode of life. (L.G.S.)

32. For what reasons is oxygen necessary to plants and animals?

Describe the method of breathing of *two* animals which you have studied belonging to two different classes of the animal kingdom. (Ox. & C.)

33. What do you mean by the term 'adaptation to environment'? Illustrate your answer by reference to any two animals with which you are familiar. (Ox. & C.)

SUGGESTIONS FOR FURTHER READING

CHAPTERS XXI–XXV

1. *Living Machinery.* A. V. Hill. (Bell.)
2. *Muscular Exercise.* Eggleton. (Kegan Paul.)
3. *Life in Ponds and Streams*
4. *The Sea Shore* } Furneaux. (Longmans, Green & Co.)
5. *The Sea Shore.* F. Martin Duncan.
6. *Underwater World.* Boulenger. (Hodder & Stoughton.)
7. *Pond Problems.* Unwin. (C.U.P.)
8. *The Natural History of Aquatic Insects.* Miall. (Macmillan.)
9. *The Romance of Insect Life.* Selous. (Seeley Service.)
10. *Concerning the Habits of Insects.* Balfour Brown. (C.U.P.)
11. *The Wonders of Insect Life* (six small volumes). F. Martin Duncan. (O.U.P.)
12. *The Haunts of Life.* J. A. Thomson. (Melrose.)

PART VI
EXCRETION

CHAPTER XXVI
THE EXCRETION OF WASTE PRODUCTS AND OF WASTE ENERGY

THE FORMATION OF WASTE SUBSTANCES. Every living organism is the seat of manifold activities, many of which have now been described. In the course of these numerous metabolic processes waste products are constantly being formed which must be got rid of, many of them being harmful or even actually poisonous to the protoplasm. This giving off of the waste products of metabolism by living organisms is called *excretion.*

EXCRETION BY GREEN PLANTS. We have already studied some of the excretory processes in plants.

1. *Carbon dioxide* and *water* are formed as waste substances during respiration, and are given off to the surrounding air or water (cp. p. 265).
2. Surplus *oxygen* is given off during photosynthesis (cp. p. 65).
3. Excess *water* is given off as water vapour. This process is called transpiration (cp. p. 107).
4. In addition, various *by-products* (e.g. calcium oxalate, tannin) are formed during the metabolism of the plant, which probably represent waste products; they are not voided, but are deposited as inert substances within the cells.

EXCRETION IN ANIMALS. Animals lead more active lives than plants, and their whole metabolism is at a higher level. Resulting from these numerous activities, they form many waste substances, the chief being water and carbon dioxide, various nitrogenous compounds, and certain mineral salts. These are often removed from the body by special excretory organs, such as the lungs and kidneys of vertebrates, the nephridia and Malpighian tubules of certain invertebrate types.

EXCRETION OF WATER AND CARBON DIOXIDE. Carbon dioxide and water are formed in animals, as in plants, during respiration (cp. p. 266), and are given off from the respiratory organs, gills, tracheae, lungs, &c.; hence such organs are at the same time excretory in function.

These waste substances are formed in the tissues, and, in the higher animals, are conveyed to the excretory organs dissolved in the blood-plasma. The amount of such substances present in the blood is usually strictly controlled. If, for example, as the result of any great activity (such as running a race), the amount of carbon dioxide in our blood increases, we breathe more quickly ('pant') to get rid of it. This reaction is quite unconscious (reflex; cp. p. 223); the increased carbon dioxide in the blood stimulates respiratory centres in the brain, and these send 'messages' to the muscles of the respiratory apparatus which make the whole mechanism act more rapidly.

EXCRETION OF NITROGENOUS WASTE. INVERTEBRATE ANIMALS. Animals produce nitrogenous waste materials in a way unknown to plants, and are usually provided with special organs for ridding the body of these substances. Such organs are often large enough to be visible to the naked eye, and very obvious in dissections.

Exercises

Examine a dissection of an earthworm in which the body cavity is displayed (cp. Fig. 34). Careful observation will reveal a series of fine, whitish, coiled tubes, of which there are two in nearly every segment of the body. These are the organs of nitrogenous excretion; they are called nephridia.

Examine a dissection of a cockroach (cp. Fig. 36) in which the alimentary canal and body cavity are displayed, and observe the fine tubules (sixty or more) which open into the hinder end of the alimentary canal. These so-called Malpighian tubules are the organs for nitrogenous excretion.

It is beyond the scope of this book to discuss the nitrogenous excretory organs of invertebrate animals in any detail. Sufficient to remember that most of the higher invertebrates possess such organs. Indeed, it has been suggested, though with little foundation, that the contractile vacuoles found in many

protozoa (e.g. Amoeba; cp. Fig. 7) serve this purpose. In many worms there are tubes like the nephridia of the earthworm which, formed in the outer layer of the body, open to the exterior. Often these push backwards in the course of development, and acquire a second (internal) opening into the coelom. Such are the nephridia which you see in the earthworm. Fine protoplasmic cilia drive excretory products down these tubes and so to the exterior. Such products are removed both from the body cavity and from the blood.

Malpighian tubules are the characteristic nitrogenous excretory organs of insects. That they vary somewhat in arrangement from type to type is illustrated by the fact that in butterflies there are usually six, while in cockroaches there may be more than sixty.

KIDNEYS

In all vertebrate animals the organs of nitrogenous excretion are the kidneys. We are familiar with their appearance in mammals since sheep, pig, and ox kidneys are commonly to be seen in butchers' shops.

Exercise. Examine and sketch the dissection of a rabbit, opened to display the kidneys, ureters, and urinary bladder, which constitute its excretory organs, and are the chief channels by which this animal gets rid of nitrogenous waste.

The rabbit kidney is a dark red object about an inch long, which lies in the abdomen attached to its dorsal wall. Blood enters it by the renal artery and leaves it by the renal vein. A narrow white tube leaves each kidney and, running along the abdominal wall, opens into the urinary bladder (cp. Fig. 166). This tube is the ureter, by which urine, the fluid excreted by the kidney, is conveyed to the bladder, where it collects to be voided at intervals through the urethra. Our kidneys are similarly arranged, one on each side of the vertebral column in the lumbar region. Each is about 4 inches long and 2 broad, and from each there issues a thin white tube, the ureter, which passes along the dorsal wall of the abdomen to open into the urinary bladder. This lies in the basin of the pelvis (cp. Fig. 101).

THE FUNCTIONS OF THE VERTEBRATE KIDNEY. All vertebrate animals possess paired kidneys. The most important work of these organs is to remove waste nitrogenous matters from the blood, especially urea ($CO(NH_2)_2$) and uric acid. Often (e.g.

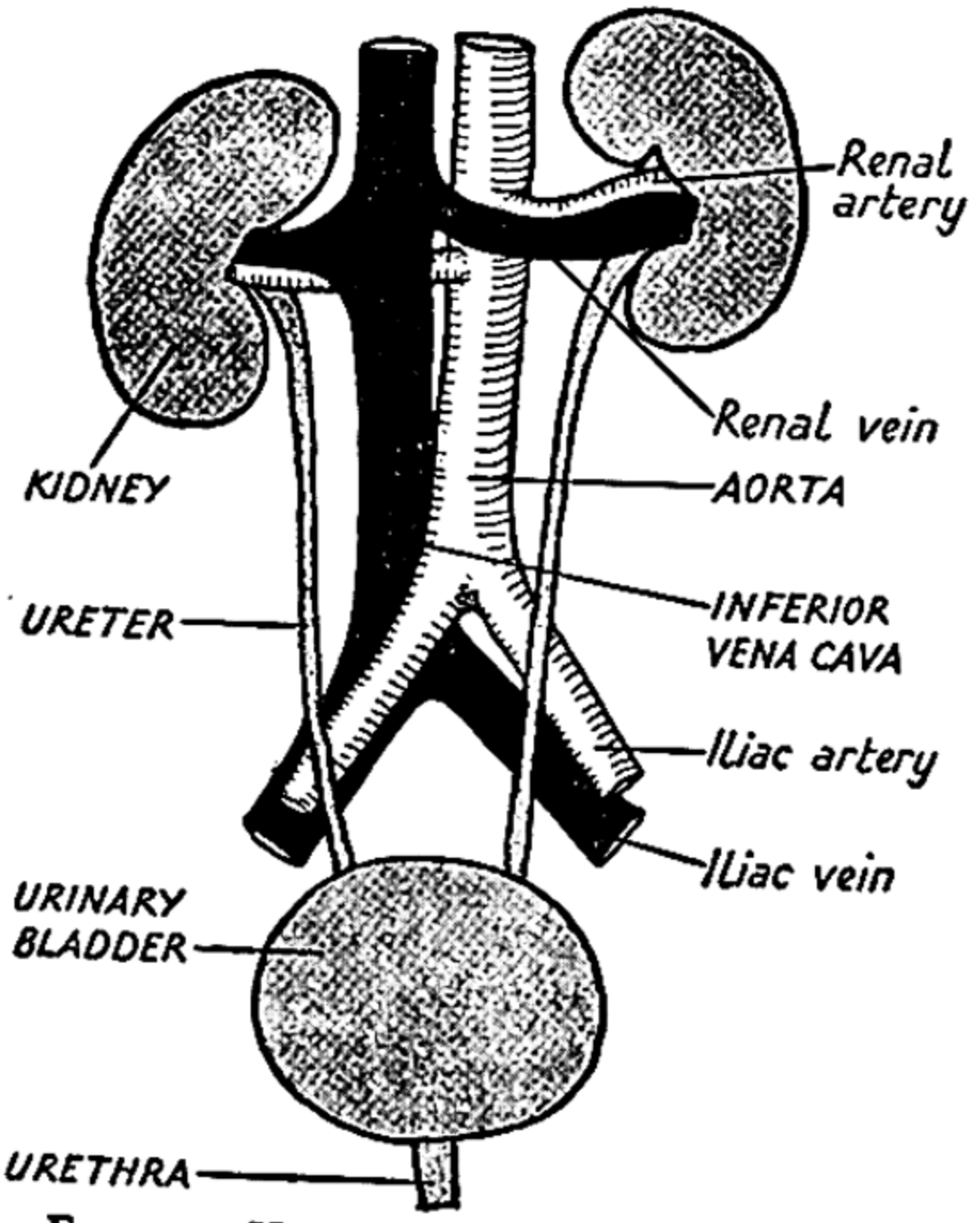


FIG. 101. Human urinary tract showing the blood supply of the kidneys (diagrammatic)

in all mammals) the excretion is a fluid (the urine) which contains the urea and other waste products in solution; but in birds and most reptiles it is a whitish semi-solid containing uric acid rather than urea as its principal nitrogenous constituent.

The kidney not only excretes this nitrogenous waste, but it also regulates the composition of the blood. The drinking of large quantities of water, for example, tends to make the blood of a mammal more dilute. The kidneys at once react by excreting an increased amount of dilute urine. Conversely, if more water

than usual is given off by the skin as perspiration (sweat), the excreted urine becomes more concentrated, containing less water. In these and many other ways, the composition of the blood is kept constant. The human adult excretes between 2 and 3 pints of urine in 24 hours, which will contain about one ounce of mineral salts, one and a quarter ounces of urea, and traces of other nitrogenous substances, &c.

ENERGY REQUIREMENTS. The kidney does a great deal of work, a gramme of kidney tissue using considerably more oxygen per minute than does a gramme of heart muscle (cp. p. 302). The amount of oxygen consumed by any tissue, since it is being used to release energy, gives us a measure of the amount of energy that tissue requires. Kidney cells are extremely active.

STRUCTURE. What is the structure of the organ which is doing all this work? The microscope shows that each kidney consists of a mass of fine, coiled tubules, held together by connective tissue, and in close touch with the blood-vessels of the kidney. Each tubule begins in a capsule, which partially surrounds a network of capillaries called a glomerulus (cp. Fig. 102). The whole structure is called a Malpighian corpuscle. From the glomerulus the blood passes, as shown in Fig. 103, through another set of capillaries which are wound round the convoluted portion of the tube. A constant exchange of materials takes place between the cells of the kidney tubules and the blood with which they are in such close contact, the final result being that waste matters are continually removed.

To make out the detailed structure of the kidney is an extremely skilled task, far beyond the powers of the ordinary reader of this book. But something can be done with a simple lens; let us see what we can discover in this manner.

EXAMINATION OF A SHEEP'S KIDNEY.

Exercises

Examine and sketch a sheep's kidney, and look on its inner concave face for the cut ends of any tubes. You should be able to identify the renal artery and vein and the thin-walled ureter, as they enter (or

leave) it. Each kidney is a bean-shaped structure, about 4 inches long and 2 inches wide (i.e. it is of about the same size as the human kidney).

Slit open the ureter with scissors, and trace it upwards into the kidney. It enlarges into a funnel-shaped bag, the pelvis of the kidney.

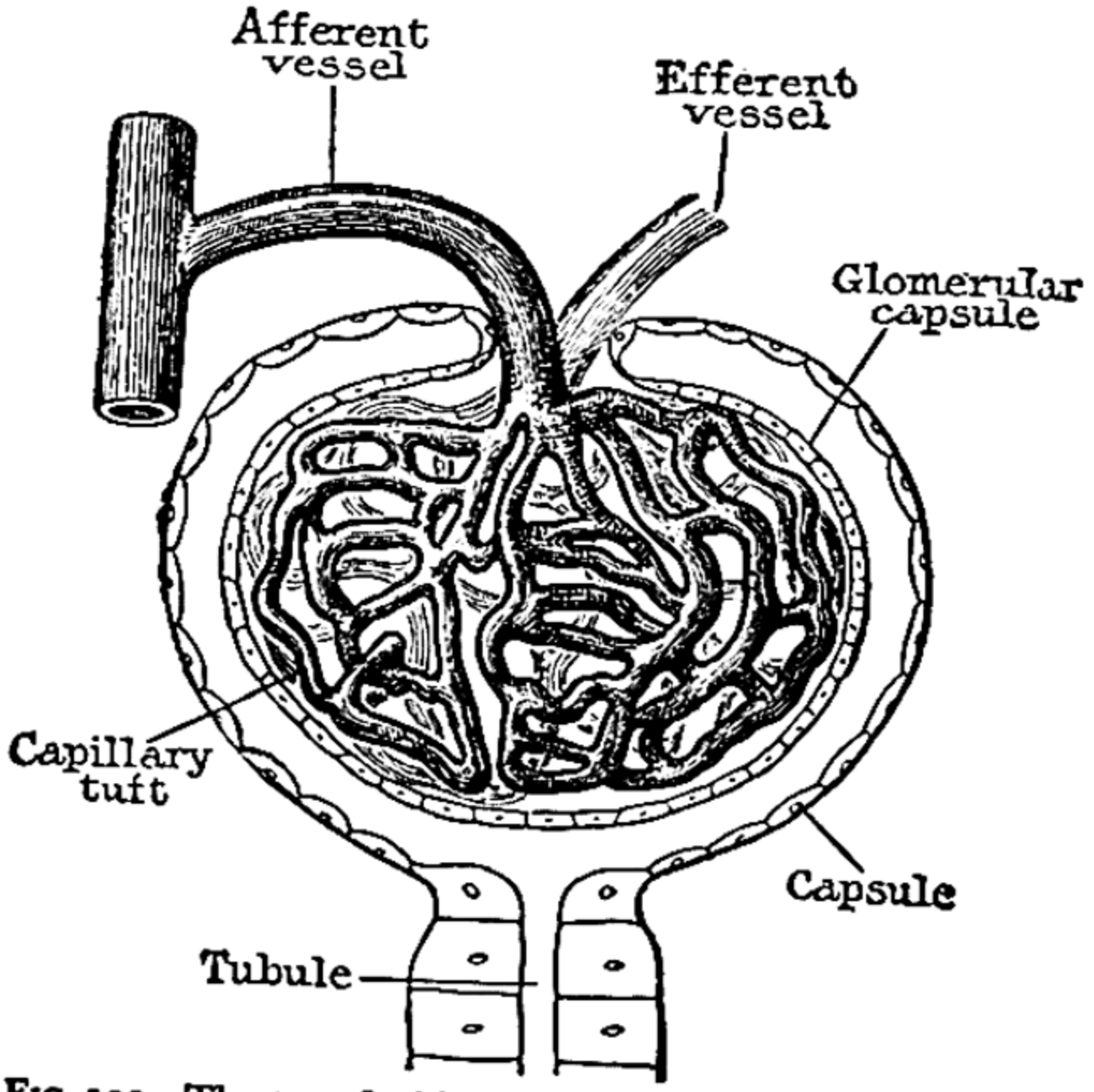


FIG. 102. The top of a kidney tubule and the related capillary tuft (very highly magnified). The tuft acts as a filter and the fluid that passes through runs down the tubule

Cut the kidney longitudinally into two halves, and sketch the structures exposed.

STRUCTURE OF MAMMALIAN KIDNEY AS SEEN WITH A LENS. Each kidney consists of an outer *cortex* and an inner *medulla*. In the cortex are the upper, more coiled ends of the kidney tubules; this cortex has a somewhat granular appearance, and under a lens a number of tiny red spots are often visible in it, which mark the position of the glomeruli.

The medulla contains the straight collecting portions of the

tubules, which give it a streaked appearance. In the sheep's kidney these tubules are arranged in about twelve groups, which form the pyramids seen in a longitudinal section. These pyramids project into the pelvis of the kidney, and it is here that the tubules discharge their urine.

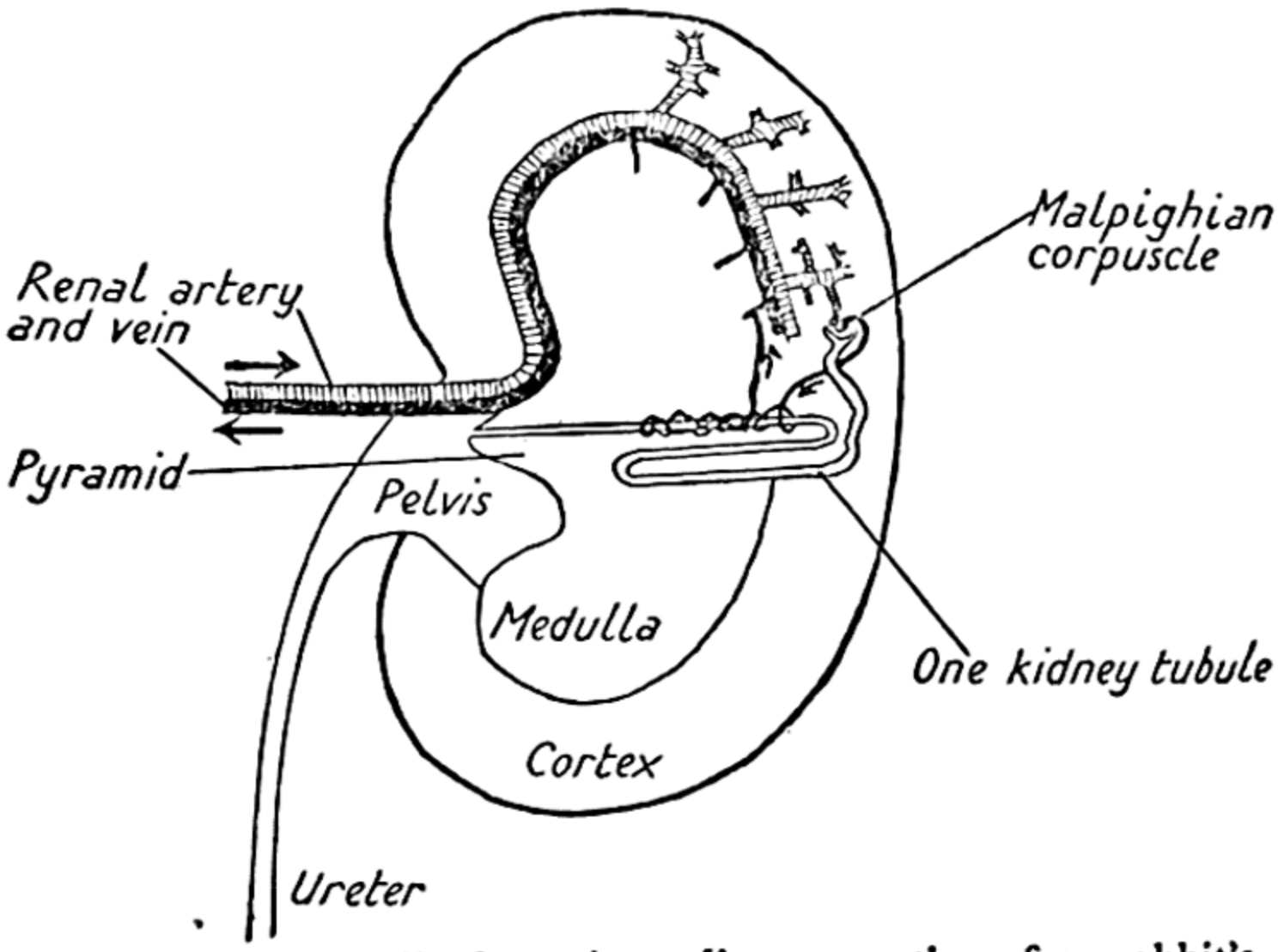


FIG. 103. Longitudinal section, diagrammatic, of a rabbit's kidney. (After Wells and Davies)

Exercise. Rcpeat the previous exercises, using a rabbit's kidney. Make drawings of the structures disclosed. They resemble those of the sheep's kidney, but there is only one pyramid.

Rabbits and sheep are mammals; you should, if possible, look at dissections showing the urinary organs of other members of this class. There is a close resemblance between them all, both in their arrangement and position, and in their minute structure. In all these animals the urinary aperture serves at the same time as the genital or reproductive aperture, and is quite distinct from the anal opening by which the faeces are discharged (cp. p. 507).

Let us now examine the urinary organs of the frog, to see

what these are like in a vertebrate animal which stands lower in the scale than the mammal.

Exercise. Examine and sketch a dissection of a frog, opened to display the kidneys, ureters, and urinary bladder.

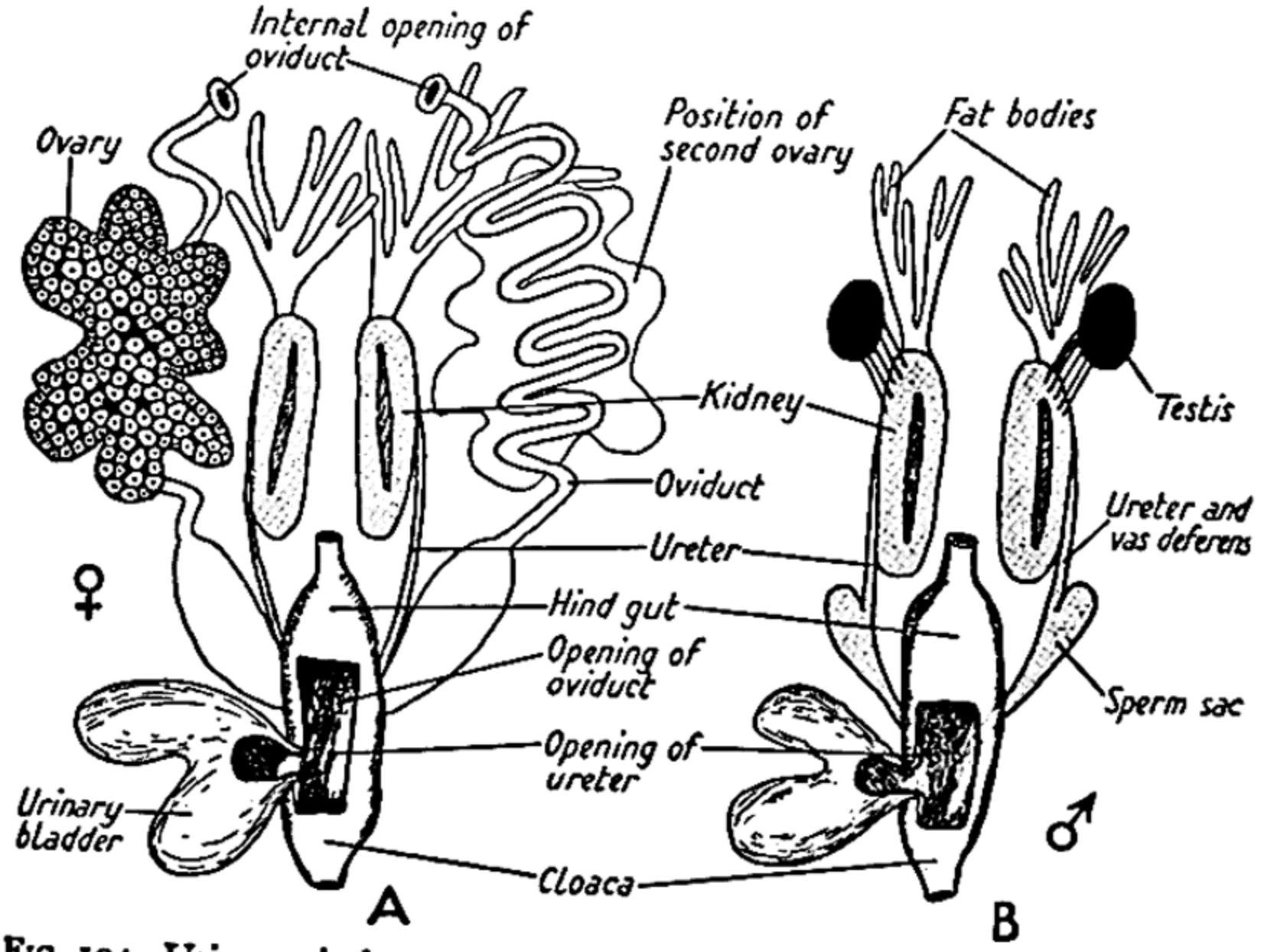


FIG. 104. Urinogenital organs of (A) female and (B) male frog. The wall of the cloaca has been partly cut away to show orifices of oviducts and ureters. (Modified, after Hogben)

ORGANS OF NITROGENOUS EXCRETION IN THE FROG. Like those of the mammal, the kidneys of the frog are paired organs lying on the dorsal abdominal wall (cp. Fig. 104). They are long and flat, much longer and less compact than is the mammalian kidney, and have not the same characteristic shape. Internally they are made up of a large number of tubules, each with a capsule surrounding a capillary glomerulus, as described on p. 335.

There is a urinary duct along the outer edge of each kidney; this does not open into the urinary bladder, however, but passes back into the cloaca (into which the hinder end of the alimentary canal also

opens). In the male frog this duct serves to transfer the reproductive cells, as well as the urine, to the exterior (cp. p. 507). The urinary bladder in this animal is a large, two-lobed sac opening out of the rectum itself on its ventral surface. Further, the urino-genital aperture is not separate from the anus; there is only one posterior orifice in the frog, the opening of the cloaca.

The blood-supply of the frog kidney is also not quite like that of the mammal. A renal artery enters each kidney, bringing blood to the glomeruli (cp. p. 325); the tubules, however, are supplied with blood from the renal portal vein, which is not present in mammals (cp. Figs. 90, 100). All the blood entering the kidney returns into the general circulation through the renal vein.

EXCRETION OF WASTE MATTER BY THE LIVER AND LARGE INTESTINE. Before we leave this study of excretion, let us recall that the liver of any vertebrate animal, in addition to its many other functions (cp. p. 171), is also an organ of excretion. The bile, of which the human liver produces about 2 pints in 24 hours, is both a digestive fluid, helping in the emulsification of fats (cp. p. 169), and an excretion. Its colouring matter, for example, represents waste products formed by the break-down of red blood-corpuscles; this pigment is excreted in the faeces, various other waste materials being got rid of in the same way. For, although the faeces contain the indigestible residue of the food, substances which cannot strictly be regarded as excretions (since they have never formed a part of the body and cannot therefore be called products of its activity), nevertheless in man they do contain, in addition, certain excreted matter. You should notice very carefully the exact difference between *defaecation* (the voiding of food remains which cannot be digested) and *excretion* (the getting rid of substances which have at some time been a part of the living body). The animal body has many methods of getting rid both of unwanted and of harmful products.

THE 'EXCRETION' OF WASTE ENERGY

LOSS OF HEAT FROM THE SURFACE OF PLANTS AND ANIMALS. The word excretion is generally confined to the getting rid of waste *matter*, formed as the result of an animal's manifold

activities; but animals also excrete waste *energy*, this being lost in the form of heat.

'The human skin excretes energy just as the kidneys excrete matter. All the heat produced in the body has to get out, and seldom does more than a fifth of it get out in the breath. The remainder goes through the skin, and its loss is regulated in such a way as to keep the temperature of the body very constant.' (*Animal Biology*, Haldane and Huxley.)

Probably all living organisms, both plants and animals, lose heat to the environment (cp. p. 262), but this loss becomes very obvious in the warm-blooded animals, the birds and mammals, since their temperature is much higher than that of their surroundings. The average temperature of birds is 40–3° C., of mammals 38–9° C.; man, with an average of 36–7° C. (98·4° F.), has a comparatively low temperature.

It is obvious that such warm-blooded animals will constantly lose heat to the surrounding air. It has been found that only one-sixth of the energy of the food eaten by a man appears as work (although occasionally, during great exertion such as that of a trained athlete, this fraction may be nearly doubled), the other five-sixths appearing as heat. We find many arrangements, therefore, for controlling this loss of heat from the surface of warm-blooded animals.

THE PRODUCTION OF HEAT BY HUMAN BEINGS. It is possible to measure the total amount of heat given off by a human being in the course of 24 hours (cp. Fig. 77). The amount varies with the occupation, &c., of the person, as the following table makes clear:

	Man	*Woman*
8 hours' sleep . .	568 Calories*	447 Calories
8 hours awake, but resting . .	739 „	582 „
8 hours' work . .	1,693 „	1,446 „
Total . .	3,000 Calories	2,475 Calories

* A large calorie (Calorie) is the amount of heat required to raise the temperature of 1000 gm. of water 1° C.

It is obvious that the daily food must be at least sufficient to supply this quantity of heat; otherwise, since energy to carry out its living processes must be obtained at all costs, the body will consume its own substance to get what it requires and will therefore lose weight (cp. p. 268). In warm-blooded animals there are many factors which to some extent control this loss of heat.

DEVICES FOR CONTROLLING THE TEMPERATURE OF WARM-BLOODED ANIMALS.

i. There is a non-conducting covering, either of feathers or fur, to hinder the escape of heat.
ii. A layer of fat is often present beneath the skin, where it forms an insulating layer.
iii. The size of the blood-vessels of the skin can be regulated; if these dilate, more blood is brought near the surface and the body is cooled; during exposure to cold, these vessels contract and less heat is lost.

In all these ways the amount of heat lost is controlled and the body temperature is kept constant. An additional regulating device is found in mammals.

iv. Sweat is excreted from the skin of some mammals; its evaporation helps to cool the body.

SWEAT GLANDS AND SWEAT.

Exercise. Examine the palm of the hand with a lens. The skin is ridged and along the tops of the ridges are numerous fine pores.

Each pore is the opening of a fine duct which runs down about a quarter of an inch below the surface of the skin, to end in a coiled sweat gland (cp. Fig. 105). There are over 2,000 of these glands in every square inch of the skin of the palm, less on other parts of the body; about 400 to the square inch, for example, on the back.

The secretion—*sweat*—is a watery, alkaline, slightly salt fluid, in which traces of organic matter and a little carbon dioxide are dissolved. How would you prove that your skin exudes moisture? Refer back to experiment 34, and see if you can adapt the method used there for this purpose. The sweat evaporates

at the surface of the skin as soon as it is formed, thus helping to regulate the temperature. When for any reason the body gets hot, as during active exercise, hot weather, &c., perspiration becomes profuse, sweat escapes more rapidly than it is evaporated, and 'beads' of perspiration appear. Increased excretion of sweat means increased evaporation, and therefore increased cooling of the surface of the body. Thus the animal is provided with an excellent safeguard against over-heating. How effective this mechanism can be appears from the fact that the temperature of a certain man born without sweat glands rose to 102° F. whenever he did physical work for a short time. To be able to carry on the work at all, he had repeatedly to soak his shirt in cold water! The mechanism fails where a saturated atmosphere stops evaporation (cp. p. 110). Hence dry heat is bearable, when the same degree of damp heat is oppressive or even dangerous.

We know how dogs, who have very few sweat glands, have to cool off the body after exercise via the mouth and tongue. This is the purpose of their familiar 'panting'.

THE SKIN—AN EXCRETORY ORGAN. We see that, in the skin, some mammals have another excretory organ in addition to those described earlier in the chapter. The amount of waste matter, other than water, which escapes in this way is negligible. The purpose of the excretion is not the getting rid of waste, but the *regulation of the body temperature.*

THE STRUCTURE OF THE SKIN IN MAMMALS. We are all familiar with the external appearance of the skin in mammals. The soft fur of a cat, the more stubbly hair of the dog, the wool of sheep, the bristles of the hedgehog, the long hairs of the human head, and the fine short hairs on the other parts of the skin show us how varied the covering of 'fur' may be. We know too that, as the result of sunburn, rowing, &c., we often raise a blister of colourless skin, which may be pricked without pain or bleeding. Such a blister consists of the upper skin, or epidermis; below it lies the dermis, in which the blood-vessels, nerves, &c., of the skin reside. These structures are made clearer by the examination of a section.

Exercises

At the nearest zoological gardens examine all the mammals and notice the variations in colour, length, texture, &c., of their coats of fur. Read up what you can about animals which exhibit *protective coloration*, the white fur, for example, of animals from the Arctic region (polar bears, foxes, &c.), and the dappled coats of those inhabiting tropical forests (lions, tigers, &c.). What can you learn about animals like the Arctic hare, who change the colour of their fur with the seasons?

Examine a prepared slide of human skin with the microscope or microprojector. Notice the epidermis, resting on the much thicker dermis, which is thrown, on its upper face, into papillae. Notice in the dermis the sweat glands and their ducts, also the hair follicles and sebaceous glands. Each hair arises singly from a papilla at the base of the hair follicle.

THE SKIN OF MAMMALS is formed of two coats, epidermis and dermis. The *epidermis* consists of several layers of cells; the outer ones, dead, flattened, and horny, are continually being cast off. They are constantly renewed by cell-divisions in the innermost layer of the epidermis, the Malpighian layer. No blood-vessels enter the epidermis; all its cells are nourished by lymph which exudes from capillaries in the dermis (cp. p. 309). Hence, as new cells are formed by the Malpighian layer, the outermost ones are pushed farther and farther from the source of supply, until they become dry and horny and, finally, quite dead.

The *dermis* contains nerves, blood-vessels, sweat, and sebaceous glands, while the hair follicles, although really inpushings of the epidermis, go deep down into it, a hair arising from the base of each. Nerve-fibres end in the papillae of the dermis and are often connected with sensory cells, forming definite sense organs. Here reside the senses of temperature, of touch in all its forms, of shape, hardness, roughness, &c. (cp. p. 228). Blood-vessels ramify in the dermis, a fine network of capillaries passing into each papilla (cp. Fig. 105 (10)). We have learned how variations in the diameter of these vessels may help to control body temperature.

This study of the skin of a mammal shows us how specialized

is its structure. The skin is only one of the many tissues which make up the body of such an animal. Yet this one organ shows far greater complexity of structure than do all the tissues together, both ectoderm and endoderm, of such an animal as a hydra.

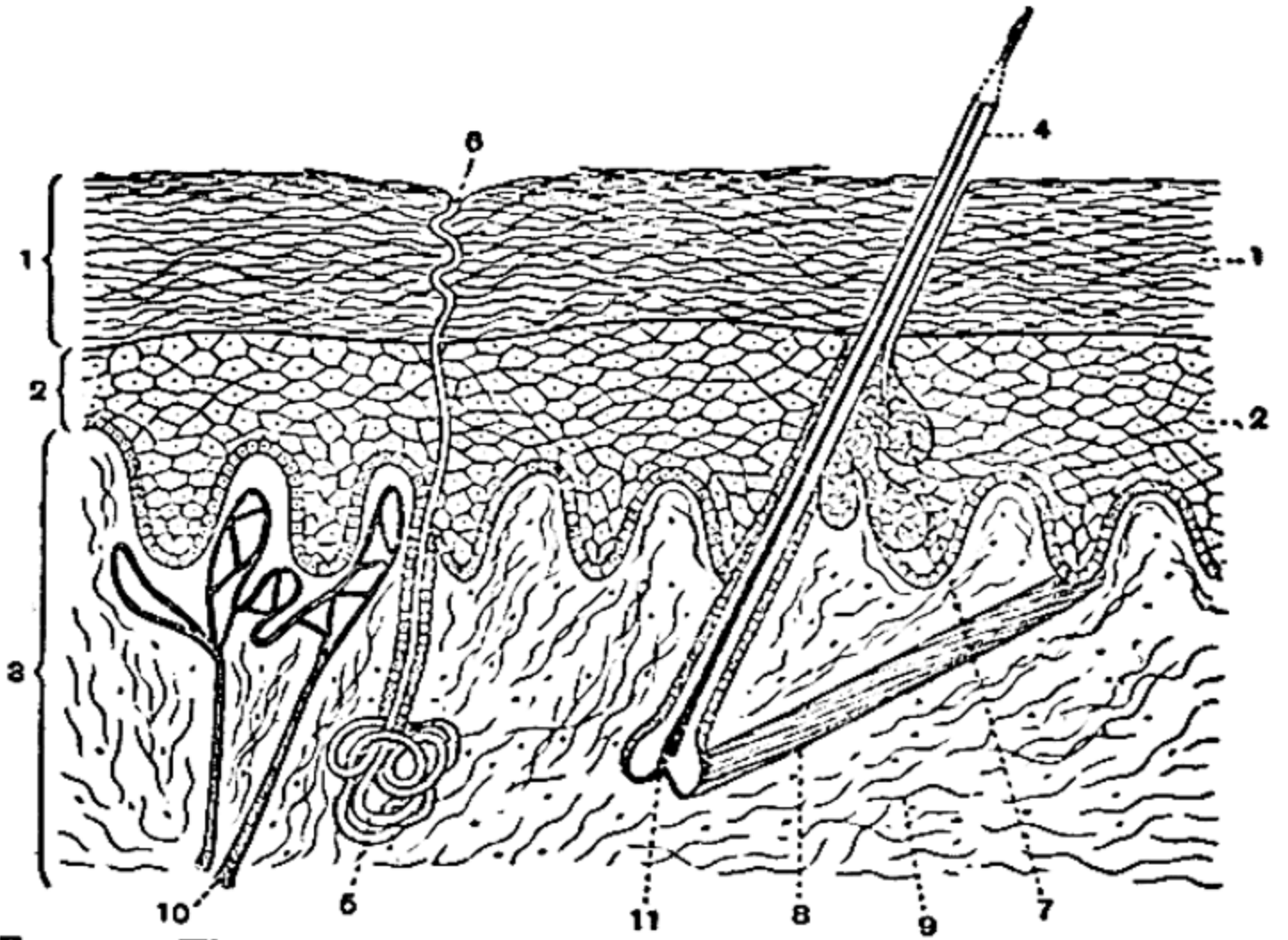


FIG. 105. The structure of the skin of a mammal as seen in section (highly magnified). 1. Horny layer of epidermis. 2. Malpighian layer of epidermis. 3. Dermis. 4. Hair follicle and hair. 5. Sweat gland. 6. Duct of sweat gland. 7. Sebaceous gland. 8. Muscles by which the hair may be made to stand on end. 9. Connective tissue of dermis. 10. Blood-vessels of dermis. 11. Hair papilla

Once more we find that, as we pass from the lower to the higher forms of life, we meet that ever-increasing complexity of structure which accompanies an ever-increasing division of labour between the different parts of the body. Each organ becomes better and better adapted for the work it has to do.

Having studied the feeding, respiratory, and excretory processes which take place in vertebrate animals, let us summarize the chief changes which the blood undergoes as it passes through the various organs of the body. The blood is the carrying fluid which transfers all the materials which the body cells use, and all the substances formed as the result of their

metabolic activities; hence every organ has some effect on the composition of the blood.

Principal Changes taking place in the Composition of the Blood as it passes through various Organs

Where change occurs	*Substances lost by blood*	*Substances gained by blood*
Lungs	Carbon dioxide Water	Oxygen
Alimentary canal	Excretory substances, e.g. colouring matter, calcium, &c., in large intestine	Food, e.g. sugar, some fats, amino-acids, &c.
Liver	Food Poisons, &c.	Food in the right concentration Excretory substances, e.g. urea, &c.
Kidneys	Urea and other waste nitrogenous products Mineral salts, &c. Excess water	
Various secretory glands, pancreas, salivary, &c.	Water and solids, from which the cells form their various secretions	Hormones, if anything (cp. p. 225)
Muscle, nerve, and all other cells and tissues of body	Oxygen, Food } for use of cells	Carbon dioxide and other waste products

QUESTIONS ON CHAPTER XXVI

1. What do you understand by an excretion? Describe experiments which show that carbon dioxide is excreted by both plants and animals, and give a short account of the process which leads to the formation of this gas.

2. Enumerate the various excretary products formed in the body of a mammal (or frog). Explain, as fully as you can, where each product is formed, and where it is excreted.

3. Give an illustrated account of the structure of the urinary apparatus of a mammal (or of the frog).

4. What do you know of the functions of the vertebrate kidney? Show how the structure of this organ fits it to perform these functions.

5. What do you understand by a 'warm-blooded' animal? What do you know of the source of this 'animal heat', and of the methods by which too great loss of heat is prevented?

6. Give an illustrated account of the structure and functions of the skin of a mammal.

7. What do you know of the way in which the temperature of your own body, of that of any other mammal, is regulated?

8. Describe the gross structure of the skin of a typical mammal, and its various functions. Compare the functions of the skin of a mammal with those of the skin of a frog. (L.G.S.)

9. Distinguish between evaporation, transpiration, and perspiration, and give some account of the function of perspiration in the life of the mammal. (L.G.S.)

10. Explain as fully as you can why physical work in a tropical climate is more difficult in a humid atmosphere than in a dry one.

11. What do you understand by respiration and excretion respectively? Describe the mechanism by which these processes are carried out in the frog. (C.W.B.)

12. Make a sketch of the specimen *B* (sheep's kidney provided), naming all the parts. Give a detailed account of the functions of this organ, explaining as fully as possible the part it plays in the physiology of the organism to which it belongs. (L.G.S.)

13. Explain how heat is produced by animals. Why do certain animals hibernate? Name any two hibernating animals belonging to different classes, and state the ways in which they prepare for hibernation. (J.M.B.)

14. What are the principal functions of the blood-vascular system? How are the same functions carried out in a flowering plant? (L.G.S.)

15. Trace the history of carbon dioxide from the time it is taken in by a plant until it is again liberated by the death and decay of an animal. (Ox.L.)

16. Nitrogen is a constituent of all living matter. Explain (*a*) how plants and animals obtain their respective supplies of nitrogen and (*b*) what becomes of this nitrogen after it has entered the living organism. (Ox.L.)

17. Distinguish between an artery, a vein, and a capillary. Describe *three* important changes in the composition of the blood which take place in *different* parts of the body. (Ox.L.)

PART VII
GROWTH

CHAPTER XXVII
GROWTH IN PLANTS

GROWTH. Food is used to supply energy; it also provides the materials needed for growth. Growth is one of the most characteristic activities of living protoplasm, but it presents many unsolved problems. We can describe the growth of an acorn into an oak tree or of a frog's egg into a frog. But to *explain* how the growth of these creatures is guided and controlled is a very different matter. What determines the very great differences in the ultimate structure, life-history, size, and length of life? There are many such problems to which the scientist can give as yet only partial and inadequate answers.

Growth always implies a permanent increase in size accompanied by the formation of new tissue. Mere increase in size is not true growth. Since organisms are composed of cells, all growth is ultimately the growth of cells. Either new cells are being formed (cp. p. 42) or cells already in existence are enlarging. This enlargement is often accompanied by differentiation, so that tissues are produced (cp. p. 29), e.g. epidermal tissue, green assimilatory tissue, conducting tissue, &c., in plants; blood, bone, nerve, muscle, &c., in the higher animals.

In the simplest organisms there is very little of this differentiation. In a Spirogyra plant, for example, the cells are all apparently alike (cp. Fig. 5). It has no definite length; any cell of the filament can divide, the nucleus leading the way. New cross-walls are always formed in a plane at right angles to the length of the filament, so that the plant body never becomes more than one cell thick.

Even growth as simple as this raises many problems. How is the division of the nucleus controlled? Why is cell-division always in the same plane? These are a few of the questions which we cannot yet answer.

GROWTH IN THE FLOWERING PLANT. The flowering plant is more elaborate in structure than a Spirogyra filament, and its growth is correspondingly more complex. Many features of this growth are easily followed in garden or laboratory. Every flowering plant begins its independent existence within a seed; seeds are produced in fruits, and these are produced by flowers, flowers being the reproductive organs of the highest plants (cp. Chapter XXXII).

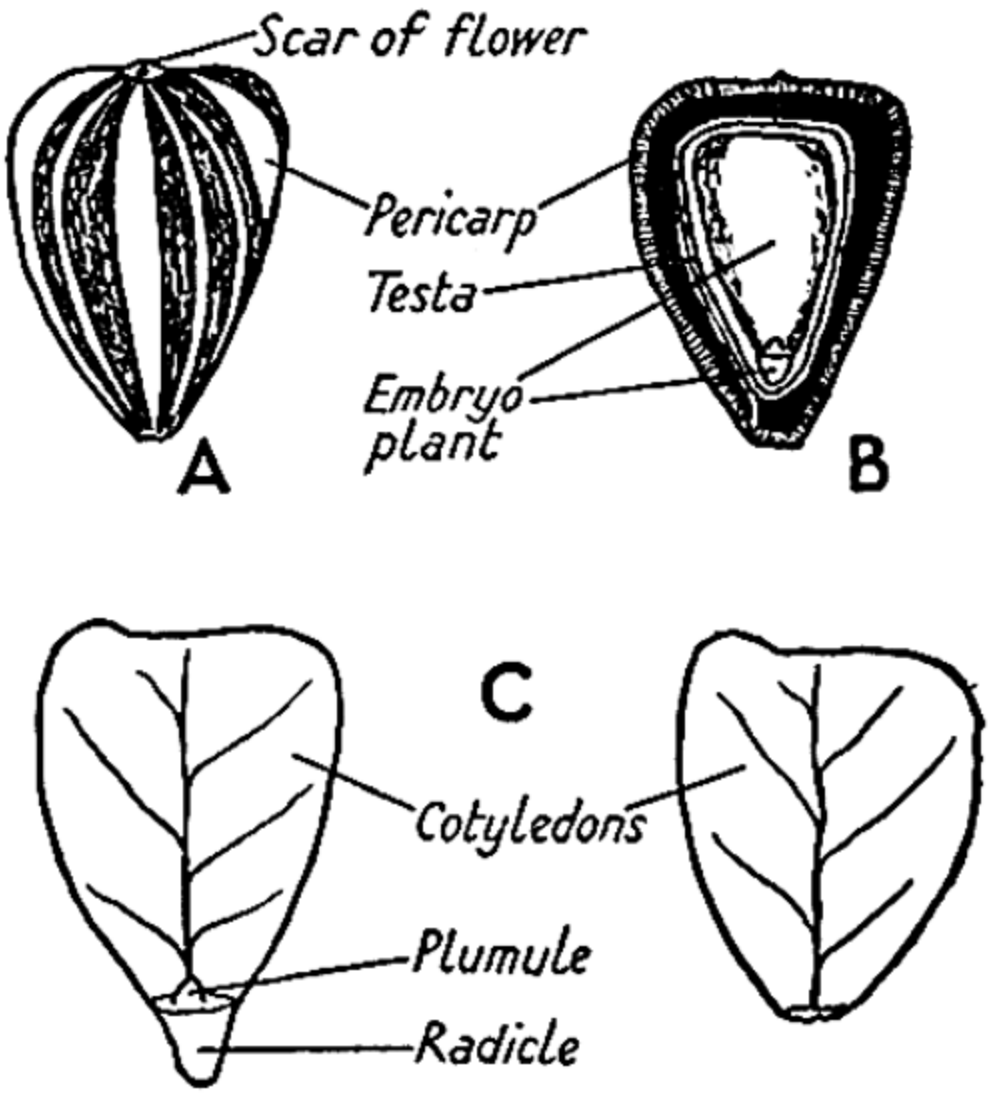


FIG. 106. THE STRUCTURE OF THE SUNFLOWER FRUIT AND SEED. The latter is dicotyledonous and non-endospermic. **A.** Achene (× 2). **B.** Longitudinal section of achene (× 2). **C.** Embryo plant, with one cotyledon removed (× 3)

SEED STRUCTURE. Seeds vary considerably in size and appearance, in the position, nature, and amount of the stored food, as well as in the structure of the contained embryo. For scientific purposes they are classified in two ways:

A. According to the structure of the embryo plant, into *monocotyledons* and *dicotyledons*.

B. According to the position of the stored food, into *endospermic* and *non-endospermic* seeds.

Let us examine seeds of these various types, and their methods of growth.

TYPE I. DICOTYLEDONOUS, NON-ENDOSPERMIC SEEDS.

The broad bean is typical of this group (cp. Figs. 17, 18).

Exercise. Repeat the examination of the broad-bean seed (cp. p. 84); also examine the seeds of pea, runner bean, sunflower (cp.

Fig. 106) (the so-called seed is really a single-seeded fruit), sycamore (the seed is enclosed in a winged fruit). In each case test the seed and determine the nature of the stored food.

In all the above seeds we observe that:

1. The seed contains nothing but the embryo plant, which usually fills the space within the testa; it is therefore non-endospermic.
2. The embryo consists of an axis and *two* lateral cotyledons. Hence the seeds are *dicotyledonous*. One end of the axis, the radicle, will form the root; the other, the plumule, grows into the shoot.
3. The reserve food is stored in the embryo itself.

TYPE II. DICOTYLEDONOUS, ENDOSPERMIC SEEDS.

Exercises

Examine the seed of the castor-oil plant, a typical member of this group. Sketch the exterior, and also transverse and longitudinal sections of the seed. Test the endosperm for oil and protein. Dissect out the embryo from the endosperm in the middle of which it lies, and sketch it.

Determine the structure of the following seeds: ash (the seed is enclosed in a winged pericarp (cp. Fig. 107 B)), buckwheat (the 'seed' is really a single-seeded fruit).

All the above seeds are fundamentally alike. We find that the seed contains a dicotyledonous embryo, and in addition a store of food, the endosperm, which lies within the seed-coat but outside the embryo. Seeds with a separate food-store of this kind are called endospermic.

TYPE III. MONOCOTYLEDONOUS, ENDOSPERMIC SEEDS.

Exercises

Revise the structure of the maize grain (cp. p. 185), and compare it with that of wheat or barley.

Examine a date 'stone' (seed). Soak a fresh seed in water for a week, then scrape away the surface on the side opposite the groove which runs down one face of the seed. A tiny embryo is disclosed, embedded in the stony endosperm (chief reserve food cellulose) which forms the bulk of the seed.

In all these seeds we find:

1. That the seed contains an embryo, and a store of reserve food, which is outside the embryo, in the endosperm.

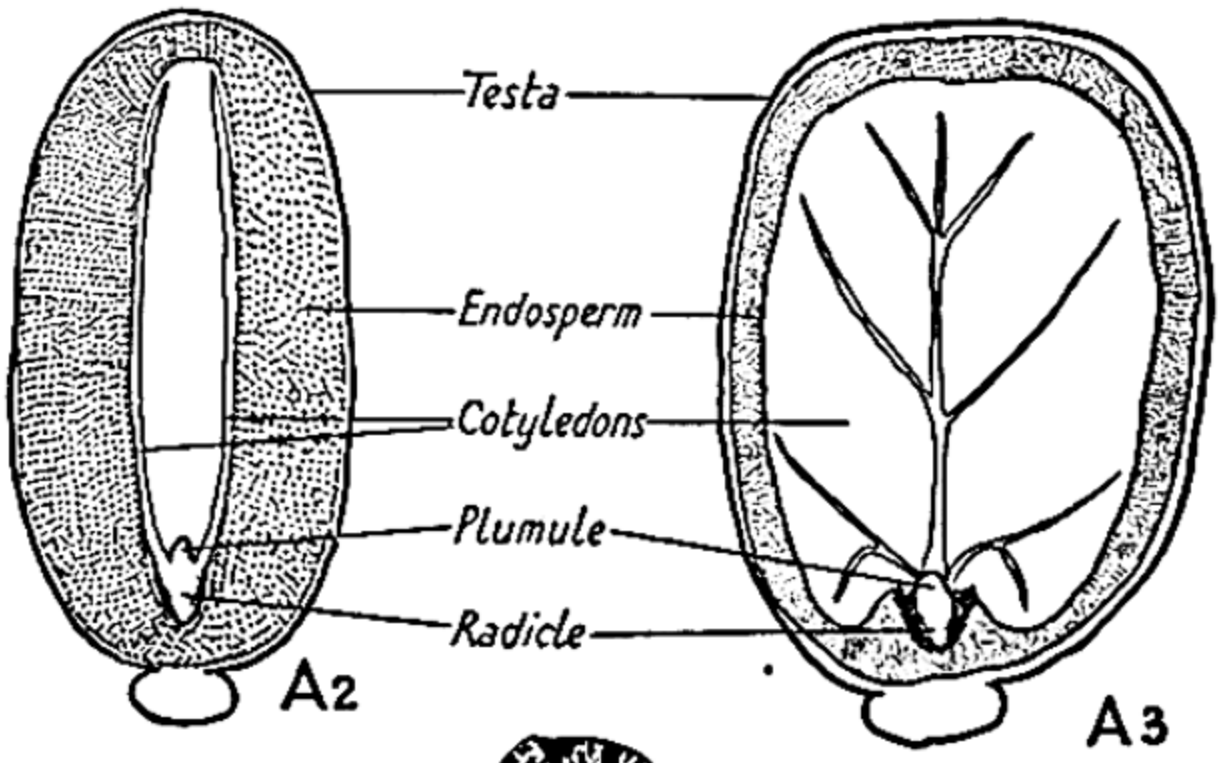


FIG. 107. THE STRUCTURE OF DICOTYLEDONOUS, ENDOSPERMIC SEEDS. **A1.** Seed of castor oil. **A2, A3.** Sections of castor-oil seed in two planes at right angles (× 3). **B1.** Winged fruit of ash (× 1). **B2.** Section of ash seed (× 3)

2. That the axis of the embryo consists of a radicle at one end and a *single terminal cotyledon* or scutellum at the other. The plumule is lateral (cp. p. 185).

This survey of seed structure shows what diversity there may

be even in such small things as seeds. Let us now see what happens when they begin to grow.

GERMINATION. Seeds usually rest for a time after their formation, the embryo plant lying dormant within. In this phase of their existence they can withstand adverse conditions, such as frost and drought, which would kill the young plant if growth had once started. The dormant period over, the seed grows if conditions become favourable; the young plant escapes from the seed-coat, pushing its root down into the soil, its plumule up into the air; leaves unfold from the plumule, and the seedling becomes self-supporting. Until this stage is reached it is fed by the reserve food which is found in every seed.

Cotyledons, which so often contain this reserve of food, are short-lived organs, and are usually discarded during the first year of the plant's life. Often they come above ground, turn green, and form the first assimilatory organs of the young plant. Such cotyledons are called *epigeal*. In other cases they remain below ground (*hypogeal*), when they do not, as a rule, escape from the seed-coat, testa and cotyledons withering together. These differences in behaviour afford a useful basis for the classification of seedling plants, a fact which will be best understood after the study of a few typical seedlings.

The germination of the broad bean is hypogeal. It has already been studied (cp. p. 87). The cotyledons remain permanently underground, their food content being gradually exhausted. Soon they wither and are cast off.

Exercises

Make sketches of the broad-bean plumule at various stages to illustrate:

(1) The escape and straightening out of the plumular hook.
(2) The formation of the first two plumular leaves, which are very simple in structure.
(3) The formation of the third and subsequent leaves, and the gradual development of both root and shoot systems.

Soak sunflower seeds, which are dicotyledonous and non-endospermic, and grow them both in gas-jars and in pots filled with soil. Make sketches of the different stages of germination.

Contrast with the broad bean the seedling of the *sunflower*,

which is epigeal. After the radicle has emerged, grown downwards, formed root-hairs, and attached itself to the substratum, the whole 'seed' (really a fruit) begins to be carried aloft by

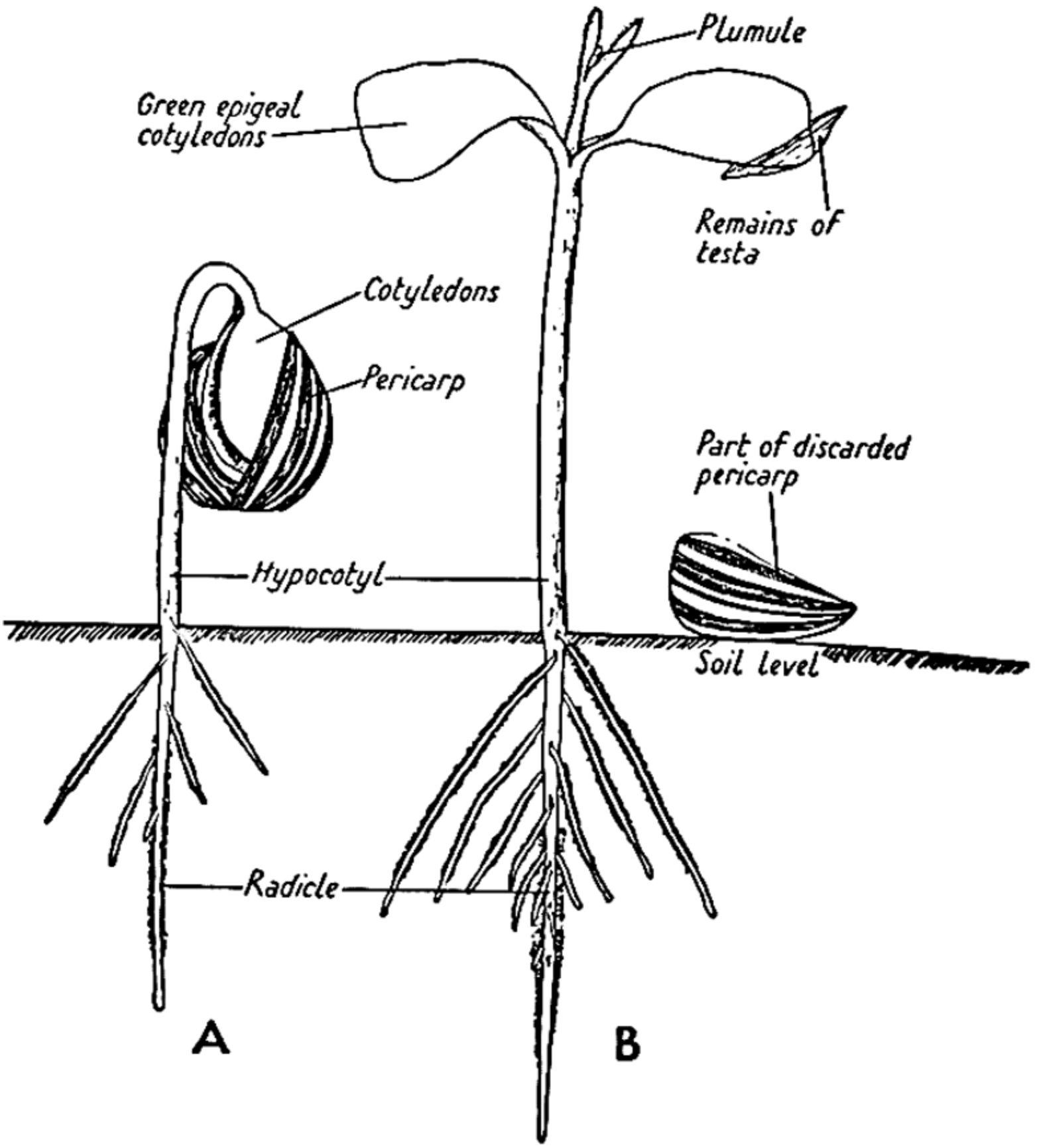


FIG. 108. Two stages in the germination of the annual sunflower (× 1)

the growth of a smooth, slightly greenish organ, the *hypocotyl*, which is somewhat thicker than the root and is formed above it. Once above ground the cotyledons enlarge, turn green, separate slightly, and throw off the pericarp and testa. They are epigeal, forming the first green leaves of the seedling.

Meanwhile the plumule, which was very minute in the dormant seed, has enlarged; it lengthens, forms plumular leaves, and so the shoot is gradually produced.

To illustrate still another method of growth in dicotyledonous seeds let us examine the seedlings of the castor-oil plant.

Exercise. Sketch various stages in the development of the castor-oil seedling.

The germination of the castor-oil seed is also epigeal; but the fact that the reserve food is not in the embryo plant, but in the endosperm around it, makes for certain differences in the behaviour of the two seedlings. There is the same development of the radicle, followed by that of a hypocotyl, which pushes the seed-case, containing endosperm, cotyledons, and plumule, above ground (cp. Fig. 109). The cotyledons, however, remain for weeks within the seed-coat, absorbing food from the endosperm. Only when this store is quite exhausted is its shrivelled remnant cast off, together with the testa (cp. Fig. 109 C). The cotyledons then turn green, open out, and serve as assimilating leaves; the plumule develops, and the young plant becomes self-supporting.

Exercise. Grow maize grains in a warm place, and sketch stages in their germination.

The germination of the maize grain. The radicle is the first organ to emerge, pushing its way through seed-coat and pericarp and rupturing the radicle sheath, the torn ends of which are visible round the base of the root. Soon the plumule appears, encased in a hard pointed sheath (the coleoptile), (cp. p. 255) which protects it as it pushes through the ground. Later this sheath is ruptured (cp. Fig. 110 B), and the first green foliage leaves appear.

Meanwhile the radicle has grown downwards, but it does not form a sturdy main root like that of a bean or sunflower. *Adventitious roots* arise very early from the plant axis; these may even be visible before germination begins. They soon become as large as the radicle, and a fibrous root system results (cp. p. 19).

The cotyledon remains below ground, digesting and absorbing food from the endosperm. When this store is exhausted, both endosperm and cotyledon wither and drop off.

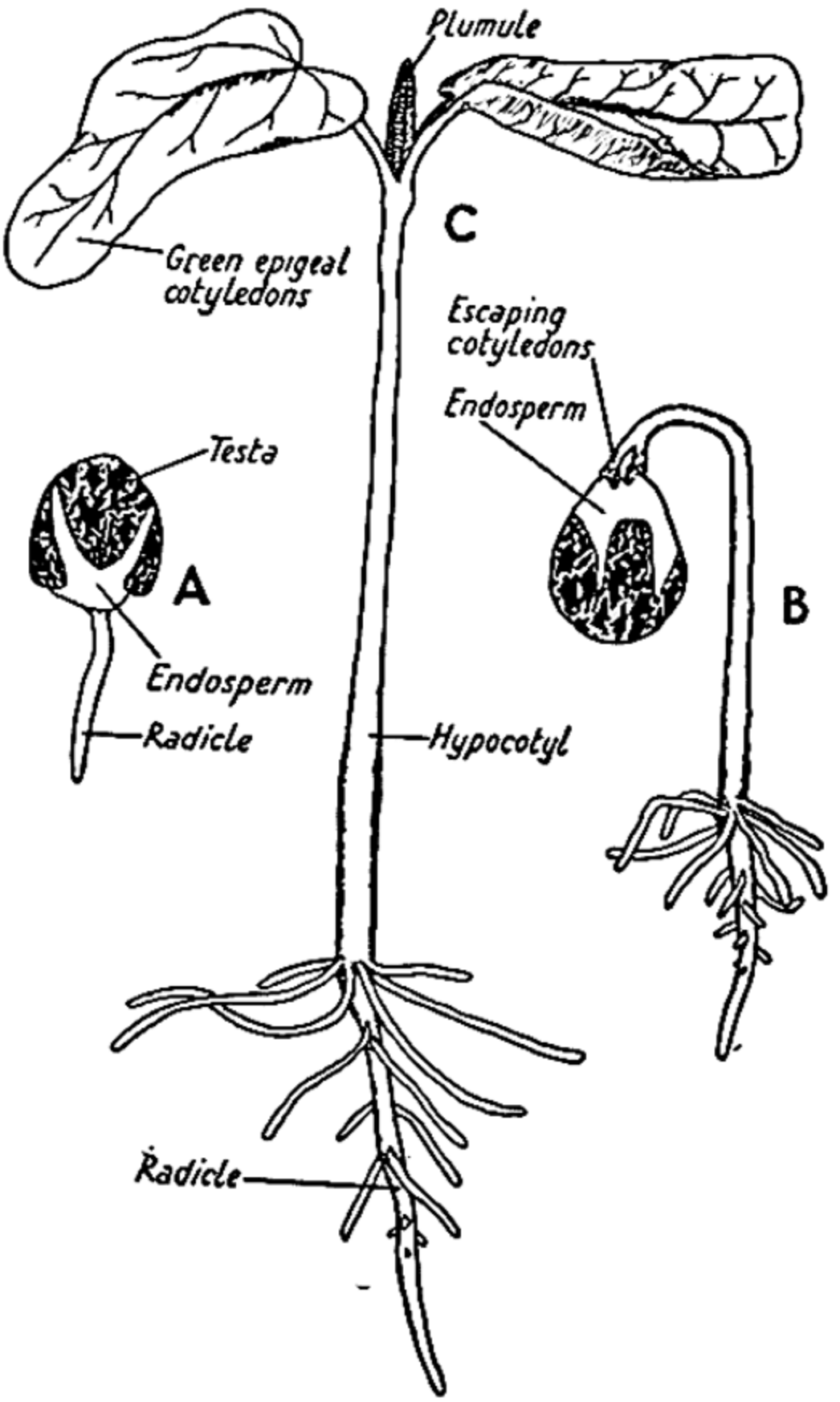


FIG. 109. Three stages in the germination of the castor-oil seed (all $\times \frac{1}{2}$)

FUNCTIONS OF COTYLEDONS. During the growth of seeds there is great variation in the behaviour and functions of the cotyledons. These are usually epigeal, but many are hypogeal. They may store food; absorb food from an outside store (the endosperm); even help to digest such a store (cp. p. 187) by

secreting enzymes into it; finally, they become the first green leaves of the plant in all epigeal seedlings.

However great the variation in the process of germination, it always results in the development of a seedling plant which, having exhausted the supply of food with which it was started in the world, is now self-supporting.

Exercise. Examine and sketch the seedlings of other common plants: sycamore, beech, stinging-nettle, goosegrass, gorse, bluebell, &c., all show interesting features. They all belong to one of the groups described above.

CONDITIONS NECESSARY FOR GERMINATION.

i. *Oxygen* is essential for healthy growth, although some seeds can live for a time anaerobically (cp. p. 271). Oxidation of food substances during respiration provides the energy necessary for all growth.

ii. *Warmth* is also essential. For each plant there is a minimum temperature, below which it will not grow, and a maximum temperature, above which it will not grow. Between these two lies the optimum or best temperature for that particular plant. This optimum varies; for wheat it is lower than for maize, for maize lower than for rice, and so on. The seeds of the Canadian maple will grow if kept on ice, but most plants require a temperature above the freezing-point for germination. The different temperature requirements of two common plants can be illustrated by the following experiment.

Experiment 98. Take three flower-pots and plant in each soaked seeds of (*a*) garden pea, and (*b*) runner bean. Place the first pot in the coolest place available, e.g. out of doors in winter; the second is kept in an unheated room, the third in some warm spot, e.g. on a radiator. The seeds in the first pot do not grow, the temperature being too low; the peas grow in the second pot, but not the beans; the beans grow in the third pot, but not the peas. The temperature on the radiator is too high for the latter.

iii. *Water* is also essential for growth; all seeds take up water, often more than doubling their original 'dormant' weight. Different plants have very different water requirements (cp. p. 124), and land plants can be over-watered as well as under-watered, as the following experiment shows.

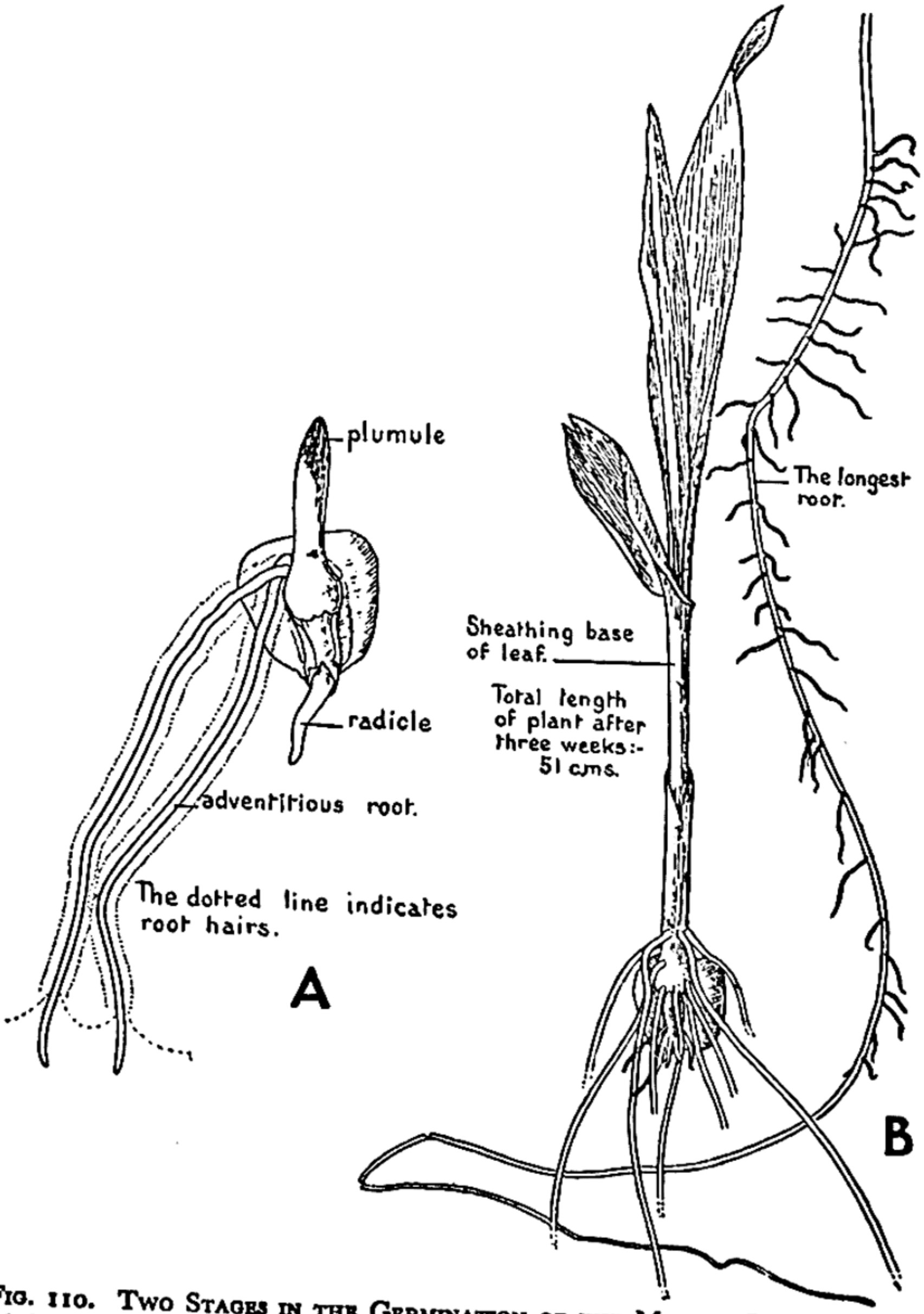


FIG. 110. TWO STAGES IN THE GERMINATION OF THE MAIZE. In B the ends of the roots have been cut off and the longest one is shown to the right of the figure (× 1)

Experiment 99. Take six small (thimble) flower-pots, fill each with fine dry soil, and plant dry pea seeds in them. Place each pot on a saucer and give varying amounts of water each day. For example the results of a typical experiment are tabulated below.

Pot 1	*Pot 2*	*Pot 3*	*Pot 4*	*Pot 5*	*Pot 6*
No water	3 c.c. daily	6 c.c. daily	12 c.c. daily	24 c.c. daily	48 c.c. daily
No growth	No growth	No growth or very slow growth	Growth quite good	Growth good	No growth

The soil is too dry for germination in pots 1 and 2, and too wet in pot 6.

Plants can be over-watered as well as under-watered. Each has a definite water requirement.

iv. *Light* is not necessary for the initial stages of germination. Many of our experiments have proved this fact, which is obvious when we consider that seeds are planted in soil. But light is necessary later for healthy growth. A plant grown in the dark becomes long-stemmed, weak, and straggly; the leaves remain small; if light is quite excluded they do not even unfold from the terminal bud. No green colour develops in such plants, light being necessary for the formation of chlorophyll (cp. Fig. 111 A). The whole plant takes on a characteristic appearance, it is *etiolated* (Fr. *étiolé*, drawn out). Such plants are incapable of photosynthesis and eventually starve to death. If brought into the light chlorophyll develops and they recover.

Exercise. Compare seedlings of bean, wheat, &c., which have been grown for the same time and under similar conditions, one set in daylight, another in a dark cupboard. Make a list of the chief differences you notice. Determine how long the etiolated plants take to become green, when they are exposed to light.

The very rapid growth in length which characterizes darkened plants (e.g. those buried deep in the soil or shaded by other plants) is obviously of great use in nature, as it enables such plants to thrust their way up into the light. How great

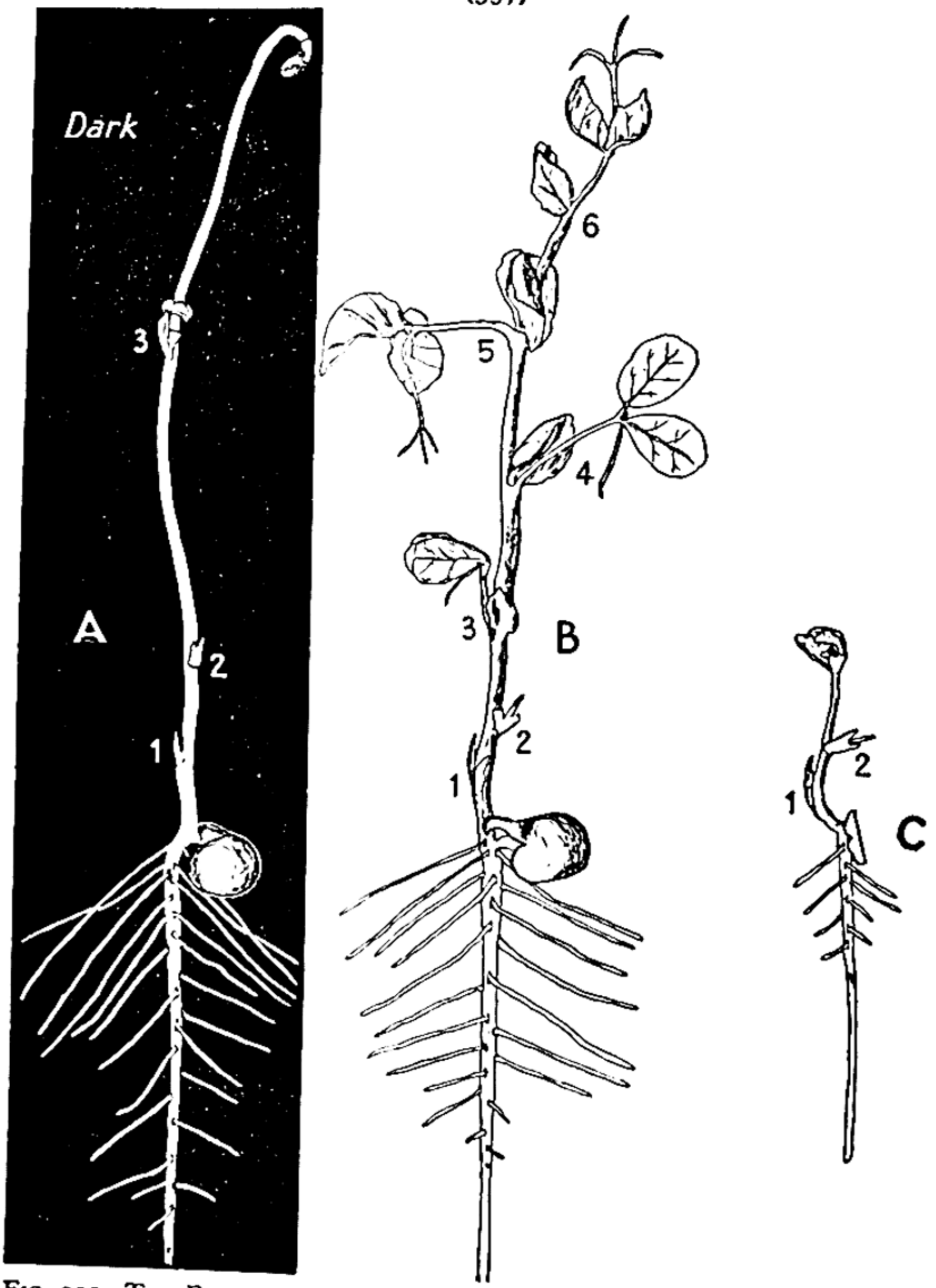


FIG. 111. THE EFFECT OF CHANGING CONDITIONS ON PLANT GROWTH. **A**, **B**, and **C** are all seedlings of the same age. **A** was grown in the dark; **B** and **C** in daylight. In **C** the cotyledons were removed a few days after germination began. (All slightly reduced)

is the effect of external conditions on plant growth is shown very clearly in Fig. 112.

Water, warmth, air, and light are all necessary for germination, as for every form of growth, whether in plant or animal. Eventually, soil or some other source of raw materials becomes necessary also. Seeds may be germinated with their roots supported by moist blotting-paper; but directly the reserve food stored in the seed is exhausted growth under such conditions comes to an end. Fig. 111 C illustrates the effect of starvation on the growth of a pea seedling.

GROWTH IN LENGTH OF THE PLANT AXIS. APICAL GROWTH. We have already learned (cp. p. 244) that the young plant axis just escaping from the seed grows in length by the formation of new tissue at the apex (cp. Figs. 65 and 66). In all apical growth three phases can be distinguished:

(1) The actual formation of new cells. In stems this cell-division occurs principally at the apex; in the root the actively dividing cells (meristematic cells) are covered by a protective root-cap (cp. Fig. 60).

(2) The cells already formed elongate. This is the phase of growth which is most obvious externally (cp. Figs. 65, 66).

(3) The cells are differentiated into epidermis, cortex, vascular tissue, pith, &c. (cp. Fig. 2). Phases (2) and (3) occur almost simultaneously, as microscopic examination will show.

By such apical growth, internal differentiation, and the accompanying development of leaves, axillary buds, lateral roots, &c., the whole plant body is gradually formed. It will be remembered (cp. p. 20) that lateral roots, unlike leaves and lateral stems, are not formed at the young, elongating root apex. They arise endogenously from that part of the root where growth in length has ended (cp. Fig. 2). The advantage of this becomes obvious when we consider that roots, to do their work, must immediately become fixed to the soil.

CHEMICAL CONTROL OF PLANT GROWTH. HORMONES. It has recently been shown that plant growth is partly controlled by certain chemical substances produced by the growing cells. We may compare these growth substances with the hormones

of animals (cp. p. 225); indeed, they are to be regarded as plant hormones.

One such substance, *auxin*, has been found in the growing



FIG. 112. THE EFFECT OF ENVIRONMENT ON PLANT GROWTH. A. Dandelion growing on plain. B. plant growing in the high Alps, drawn on the same scale

tips of the broad bean. It causes elongation of the stem, both in intact plants and in isolated bits of stem; further, it has been shown that this auxin, while stimulating the growth of the terminal bud, actually inhibits the development of the lateral buds below.

Plants produce more lateral buds than can ever develop, but their growth can be stimulated by removal of the terminal bud. Hedges are clipped, fruit trees and roses pruned, for this purpose.

The growth of the whole plant is co-ordinated—it is a living organism, a unity; and this co-ordination is brought about, at least in part, by chemical substances which pass from one part of the plant body to another.

GROWTH IN THICKNESS OR SECONDARY GROWTH. The most cursory examination of any large plant shows that its axis grows in thickness as well as in length. A two-year-old horse-chestnut seedling, for example, had a stem 1·7 cm. in circumference, at a distance of 3 cm. above the ground; the circumference of a ten-year-old stem was found to measure 6·8 cm. at the same level.

A young dicotyledonous stem consists internally of pith, a number of vascular bundles separated by medullary rays, cortex, and epidermis (cp. Figs. 2, 22). Between the wood and bast of the vascular bundle is a narrow band of thin-walled, flattened meristematic cells, the *cambium* (cp. Fig. 22 A). All the other cells of the bundle are now mature, only these cambial cells are capable of further growth.

Growth in thickness begins by the cutting off of a band of cambial cells across each medullary ray (cp. Fig. 113 A), so that the cambium, as seen in transverse section, becomes a complete ring. This forms new cells, both internally and externally; the inner ones are transformed into secondary wood (xylem), the outer ones into secondary bast (phloem). A compact mass of wood is thus produced which, in woody perennials, grows in thickness year by year.

Roots increase in thickness in a similar manner.

ANNUAL RINGS. In our large forest trees this growth in thickness continues as long as the tree lives. Every year in the spring, a new ring of wood is added by the cambium internally, of bast externally. The wood elements have thick walls, and remain permanently in position; the sieve tubes are thin-walled and living, and soon die. Hence an old tree-trunk consists chiefly of a mass of wood. This wood, in transverse section, is seen

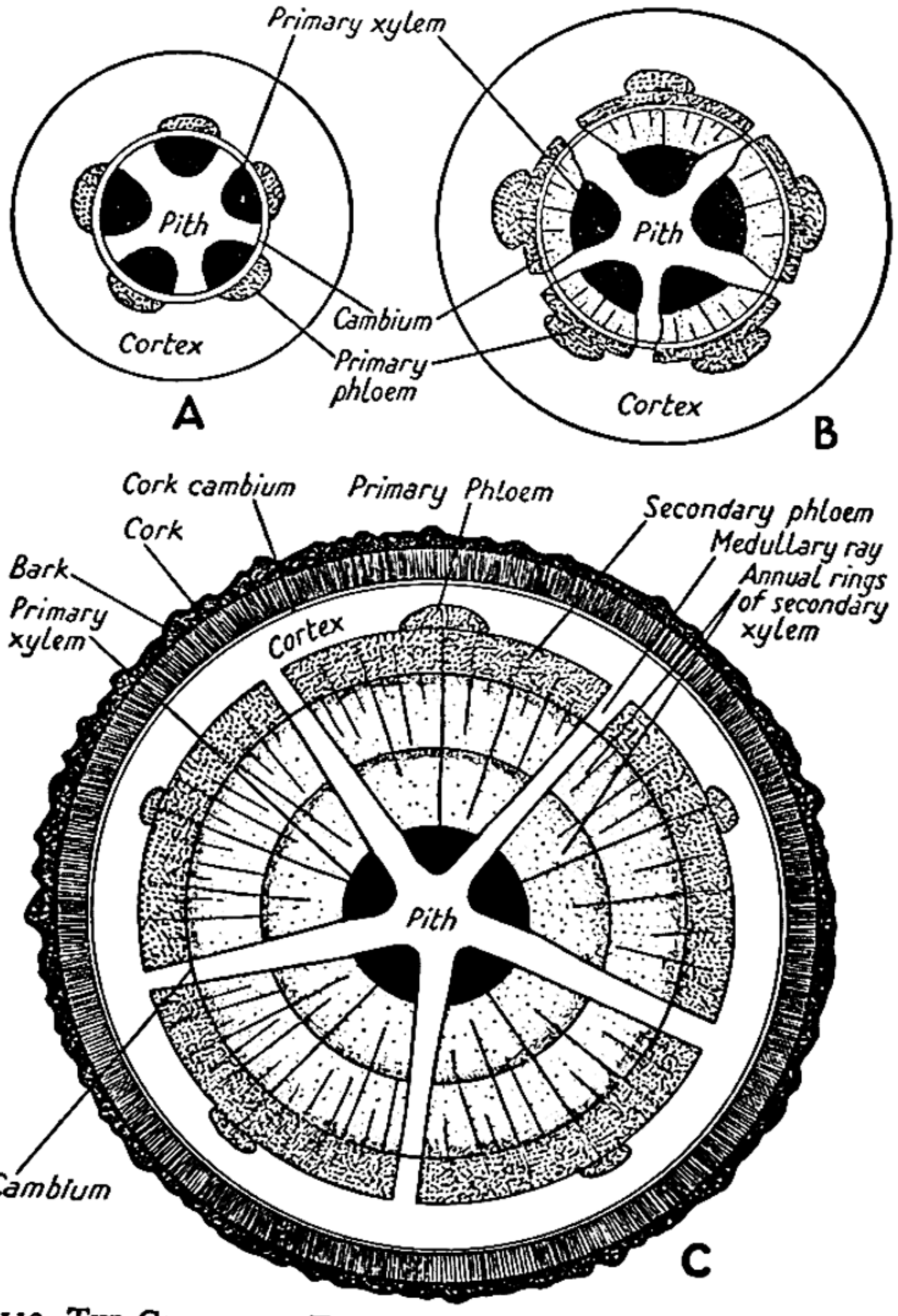


FIG. 113. THE GROWTH IN THICKNESS OF A STEM. **A.** Ring of cambium formed. **B.** Secondary growth beginning. **C.** Two annual rings have been formed

to be arranged in rings; the number of the rings tells us the age of the tree (cp. Fig. 114).

The first wood formed in the spring has large vessels for the rapid transport of water, &c., to the opening leaves; that formed

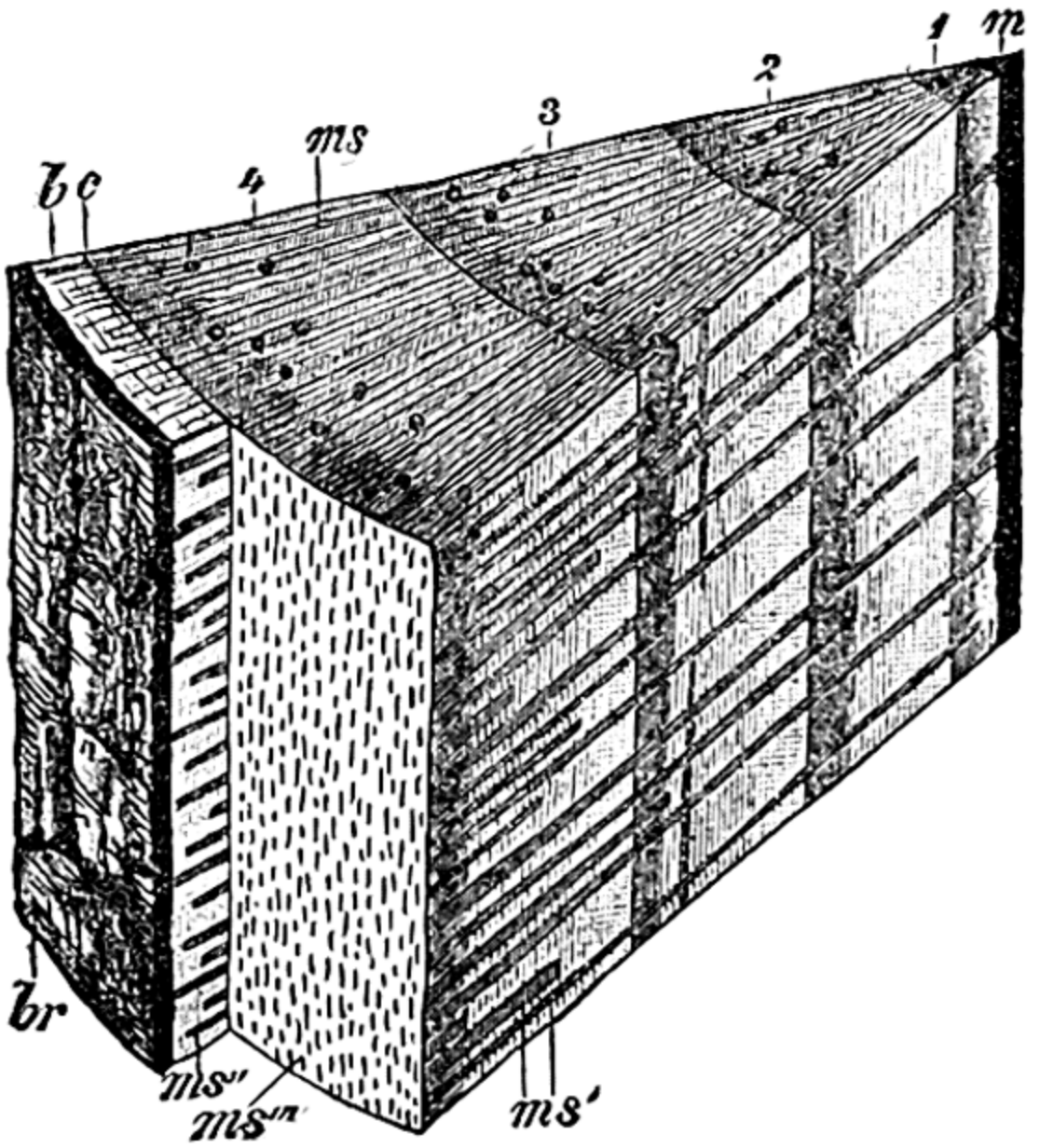


FIG. 114. A FOUR-YEAR-OLD PINE STEM. Observe the four annual rings of wood (1–4), the medullary rays (shown in transverse, *ms*, radial, *ms'*, and tangential, *ms'''*, views). Outside the wood is the cambium (*c*), the bast (*b*), and the bark (*br*). Bast and bark have been removed from one portion of the section

later in the year is more compact, serving for support rather than for transport. This difference between spring and autumn wood, which characterizes all trees of the temperate zones, causes the ringed appearance with which every one is familiar.

MEDULLARY RAYS. Cells formed by the cambium become differentiated into woody elements, vessels, fibres, &c., or into sieve tubes, bast fibres, &c., structures either for transference of water and dissolved substances, or for support (cp. p. 97).

A certain number of living cells are usually left, however, among the non-living elements of the wood and bast. These form medullary rays, which extend outwards from the cambium in both directions, the chief rays passing right across the secondary tissue from pith to cortex (cp. Figs 113, 114). They are composed of cells which are elongated radially (i.e. *across* the stem), and they serve for the storage of food materials as well as for transport. One of the substances thus transported is oxygen, which passes across the stem from the lenticels on its surface to the living cells, e.g. cambial cells, &c., of the interior (cp. p. 274).

BARK AND CORK. Continual growth in thickness of root and stem will obviously compress the tissues lying outside the growing layer (cambium). In a young stem these keep pace for a time, but ultimately become stretched and torn. Very soon a second cambium, the *cork cambium*, becomes active near the surface of the stem, which adds layers of cork cells to the periphery of the stem, as secondary wood and bast are formed within (cp. Fig. 113 C). Cork is an extremely impervious substance which is deposited in the walls of the cork cells. No water, food, or oxygen can penetrate it; hence all tissues outside the cork, and the older cork cells themselves, continually die away and are cast off as the bark.

Exercises

Cut thin sections from one-year-old and three-year-old lime or pine stems; immerse them for a few minutes in a solution of aniline hydrochloride; mount on a slide in glycerine, examine with a lens, and draw the two sections.

The first shows one ring of wood only; the second has three annual rings. Notice pith, primary wood, secondary wood, bast, cork, &c.

Examine and sketch a block of wood, cut to show both transverse and radial longitudinal sections. In the transverse section notice the annual rings, with their alternation of more open (spring) and more compact (autumn) wood. Notice the numerous rays running across the stem, some of them running right across from the centre. Look for traces of phloem, cork, and bark (cp. Fig. 114).

Examine and sketch the longitudinal section; notice particularly the medullary rays, which appear as broad, shiny streaks.

HEART-WOOD AND SAP-WOOD. In some old trees the central wood is harder and darker than that outside. In such stems conduction of water takes place entirely through the sap-wood. The heart-wood gives added strength and rigidity.

QUESTIONS ON CHAPTER XXVII

1. Describe with labelled diagrams the structure and germination of any named seed. (C.W.B.)

2. Describe by means of a series of labelled drawings the stages in germination of one named seed. (C.L.)

3. How would you test any given seed to determine the nature of the stored food? How does this food compare with that stored in a fowl's egg? State briefly the purpose for which each of these stores is used.

4. Write a short essay on the structure and functions of cotyledons.

5. Write short notes on the following: endosperm, epigeal cotyledons, scutellum, coleoptile.

6. How would you distinguish a monocotyledonous from a dicotyledonous plant (*a*) in the seed stage, (*b*) when the two plants were mature?

7. Describe carefully what you mean by a seed and a fruit. Describe the structure of the grain of the maize (or wheat). (J.M.B.)

8. Compare and contrast the development of the plant from a seed, and the development of the tadpole from a frog's egg. Is there any resemblance between the two processes?

9. Describe experiments you have performed to investigate the conditions necessary for the germination of seeds, and state the results of your experiments. (L.G.S.)

10. Describe the way in which the stem of a dicotyledonous tree grows in thickness, explaining the formation of annual rings. (L.G.S.)

11. How could you determine experimentally the region of greatest growth in length of a young pea or bean plant? What functions are performed by the root-hairs? Comment on the fact that root-hairs lie *behind* the region of maximum elongation. (L.G.S.)

12. Of what advantage is it to a large tree, such as an oak or sycamore, to branch so profusely? How are such trees enabled to withstand the rigours of winter? (C.W.B.)

13. Write a short essay on germination. (L.G.S.)

14. By means of labelled diagrams only, show (*a*) the external appearance and internal structure, and (*b*) three progressive stages

in the germination of a grain of wheat *or* maize. Explain the work done by the cotyledon during the germination of the grain selected. (J.M.B.)

15. In what region of a shoot of a tree does growth in length occur? How could you show experimentally that your statements are correct? Mention any differences, in respect of the position of the growing region, between the branch of a tree and the limb of a mammal. (Ox. & C.)

16. Describe what experiments you would perform to ascertain the conditions under which seeds germinate. (Ox. & C.)

17. How do roots differ from shoots in their general structure and functions? Illustrate your answer by reference to the roots and shoots of a named herbaceous plant and a named tree; make explanatory sketches. (C.L.)

CHAPTER XXVIII

GROWTH IN PLANTS (*continued*)

GROWTH AND FORM

VARIATIONS IN PLANT FORM. In the last chapter we examined processes of growth which are common to most flowering plants. In spite of these common features, the ultimate forms of such plants are extremely diverse. They are adapted to different climates and habitats (cp. p. 88); they have very different lengths of life, including, on the one hand, tiny short-lived ephemerals, on the other the oldest and largest living things. The General Sherman tree of California is believed to be nearly 4,000 years old; it is 279 feet high and its trunk is 36 feet in diameter.

'All our European and American history are but events of yesterday to this patriarch of the organic world, which now towers higher than a twenty storey building and is still growing.' (Moon, *Biology for Beginners*.)

To some slight extent these differences in form and life-history can be correlated with external conditions (cp. Fig. 112). Tree growth is most luxuriant in warm, moist regions; we should not expect to find a tree like this 'General Sherman' on the Arctic tundra. Every living thing has its place and season, and many possess special structures which enable them to survive through periods when conditions are unfavourable.

PLANT GROWTH IN RELATION TO LENGTH OF LIFE. Flowering plants are either annual, biennial, or perennial.

Annuals complete their whole life in a single season; having flowered and produced seeds, the whole plant dies. Sometimes they are so short-lived that several generations are produced in a single growing season, e.g. shepherd's purse. Such plants are called *ephemerals*. Deserts become covered with ephemerals after any shower of rain, their seeds having lain dormant for years in the hot dry sand. Among familiar cultivated plants which are annuals are wheat, oats, barley, &c., peas, and beans; while wild annuals include all the common cornfield weeds,

such as cornflowers, poppies, &c., and most of the weeds of cultivated soil, e.g. chickweed, groundsel, shepherd's purse, and so on.

Biennials live for two seasons. During the first year their growth is purely vegetative; they form leaves, and by the end of the season have stored up a certain reserve of food. In some very familiar vegetables (carrot, parsnip, turnip, beetroot, radish, &c.) a large amount of food is stored in this way, often in the main root (e.g. carrot, beetroot). It is this food-storing habit which has led to their cultivation.

In the second year of life biennial plants flower and produce seed, using up their food store in the process. These plants, like the annuals, only flower once, and then the whole plant dies.

Perennials live for many years, and when once flowering starts it usually continues for many seasons. These plants are of two kinds:

(*a*) *Herbaceous* perennials, which produce no permanent woody shoot system.

(*b*) *Woody* perennials, the shrubs and trees.

Herbaceous perennials show very great variations in form. Yet under all this diversity there is one common feature. The whole plant is reduced in size as the unfavourable season of the year approaches, and it passes that season (e.g. winter, the dry season, &c.) in a state of dormancy, either entirely underground, as do bulbous plants, or with some small part of the plant body on or above the surface of the soil (e.g. dandelion).

In studying perennials their winter as well as their summer form must always be kept in mind.

Exercise. To obtain some idea of the great range of form exhibited by herbaceous perennials, examine the following plants (or others of similar habit) before you read what follows. Where possible the whole life-history, including development from the seed, should be studied, and the life of the plant should be followed for at least one season. Make illustrated records showing the life and structure of each plant: dandelion, creeping buttercup, strawberry, Solomon's seal, crocus, potato, tulip, bluebell.

THE GROWTH FORMS OF HERBACEOUS PERENNIALS

THE ROSETTE PLANT. Dandelions and daisies are typical rosette plants, forming a tight cluster of leaves just above the surface of the earth This lowly habit and rosette form protect them from drying winds, from browsing animals, even from

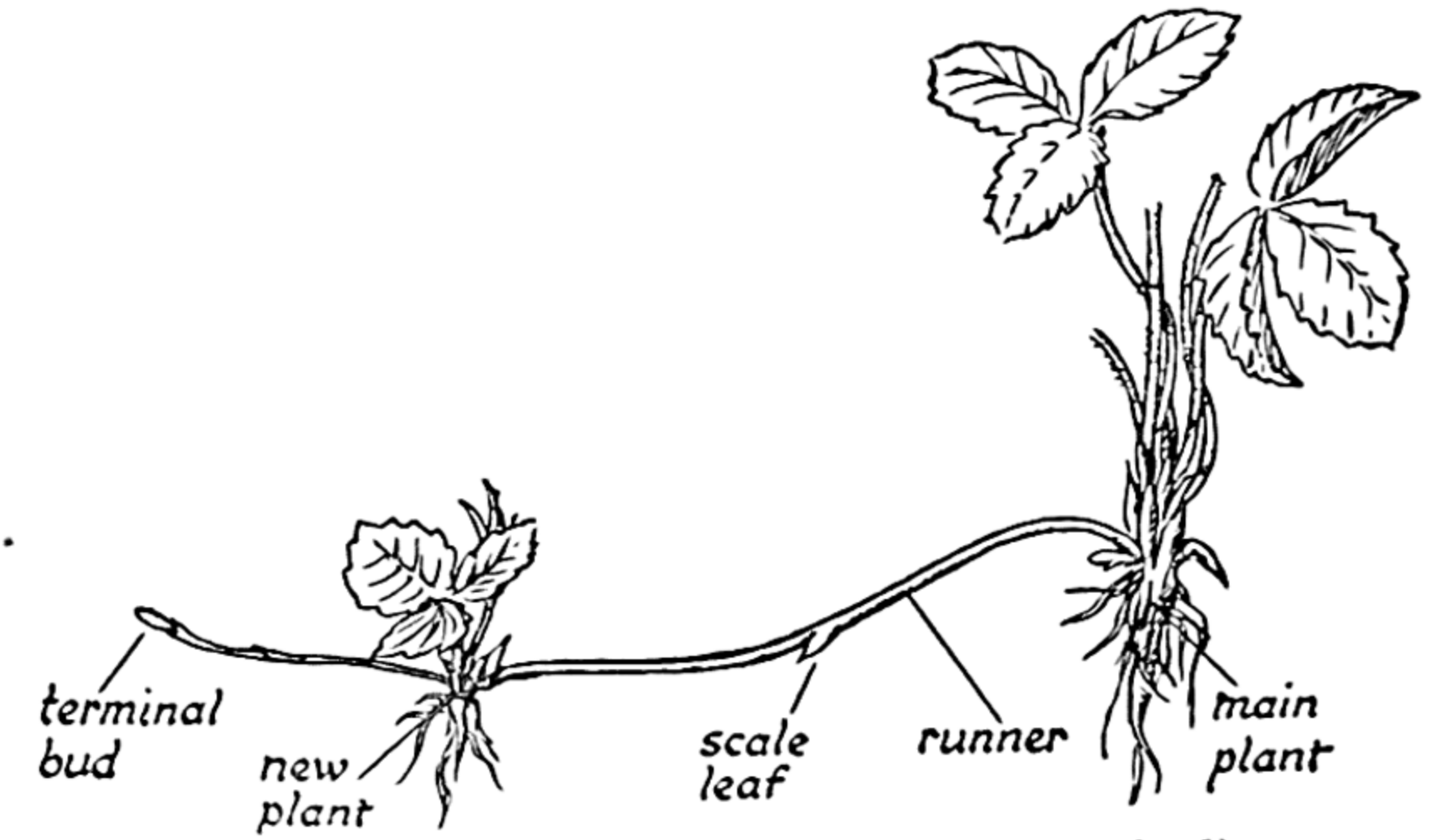


FIG. 115. The strawberry plant with runners (× ⅓)

man and his lawn-mower. Such weeds are therefore common in lawns and pastures.

THE PLANT WITH CREEPING STEMS. Although most plants form upright stems, this is not universal. The creeping buttercup is an herbaceous plant whose stems straggle over the surface of the ground, rooting themselves as they go; ground-ivy and creeping jenny are other familiar plants with this habit of growth, which is by no means uncommon. Such horizontally growing stems are diageotropic and diaheliotropic (cp. p. 250); they produce adventitious roots from the nodes, and may invade and fix themselves to a comparatively large area of soil.

THE PLANT WHICH FORMS RUNNERS. We may take the strawberry plant as typical of this mode of growth. The original plant has a short thick upright underground stem (root-stock;

cp. Fig. 115), from the base of which adventitious roots arise, while at its apex is a rosette of foliage leaves. Certain axillary buds grow out into curious thread-like stems called runners; each runner produces nothing but one or two tiny scale leaves until it is 2 or 3 feet long, when from its apical growing point a new rosette of leaves and new adventitious roots arise. From these young plants the process may be continued by the formation of more runners.

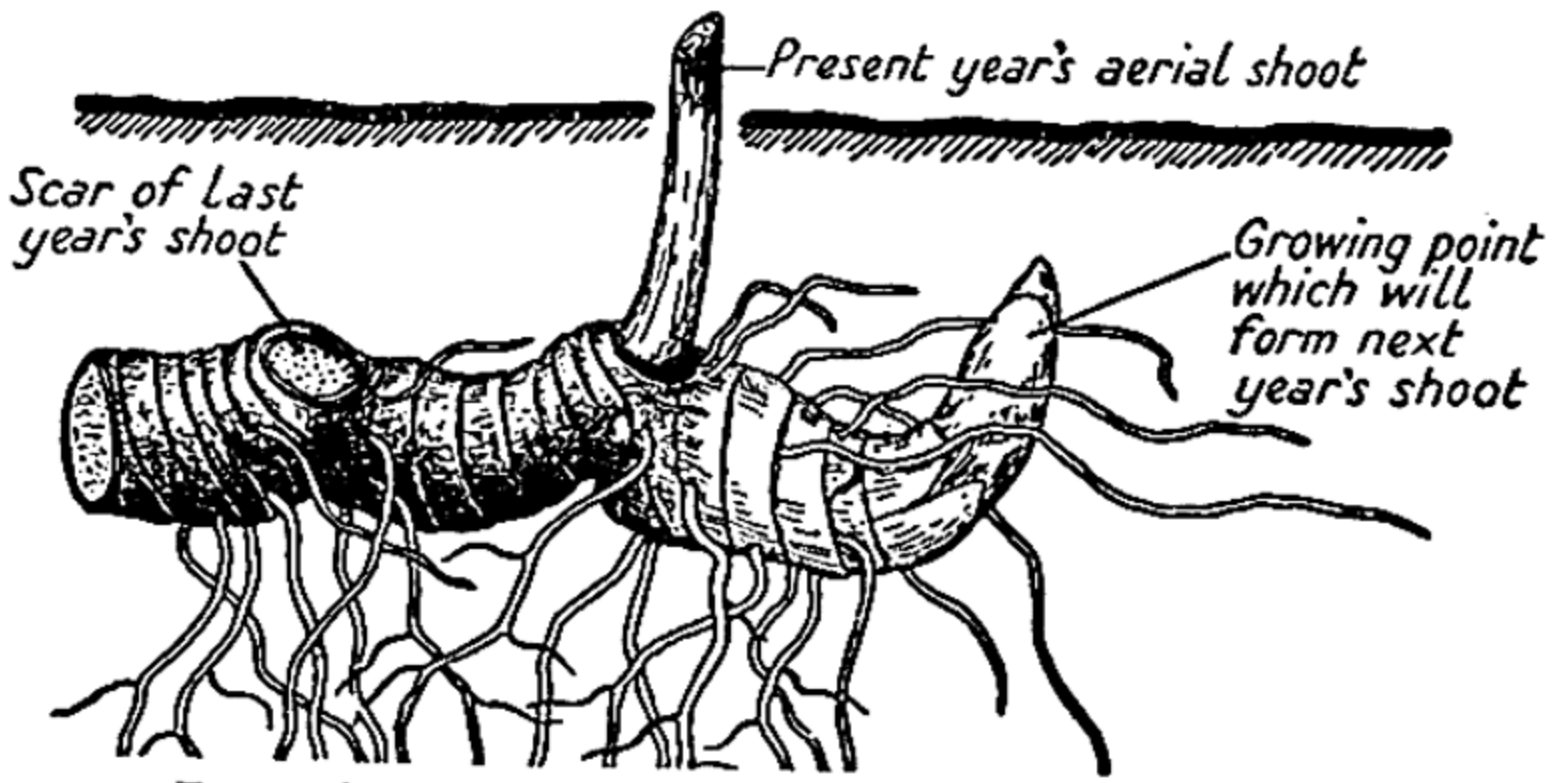


FIG. 116. Part of the rhizome of Solomon's seal (× 1)

THE PLANTS WHICH FORM RHIZOMES. Many herbaceous perennials have a portion of their shoot system underground, where horizontally growing stems, called rhizomes, live on from year to year. Solomon's seal (cp. Fig. 116) is a typical plant with this method of growth. All its perennating stems are buried in the soil; they bear scale leaves and adventitious roots, and branches arise as buds in the axils of the scale leaves. Each season the terminal bud of the rhizome grows upwards, producing an aerial shoot which bears foliage leaves and flowers. At the end of the year's activity this aerial shoot dies away, leaving on the underground stem a very characteristic scar (cp. Fig. 116). The growth of the rhizome is continued underground from an axillary bud.

Plants with this habit of growth are very firmly fixed in the soil, and may even hold loose soil together. Hence they are

common on river banks, on the sandy sea-shore, in fen and marsh land—wherever the soil is loose and shifting. Many rhizomes, like those of Solomon's seal and iris, are thick and serve to store reserve food, as well as to continue the growth of the plant underground. Others, e.g. those of couch-grass, Psamma, anemone, and lily of the valley, are quite thin.

Exercise. Examine and sketch the rhizome of couch-grass or Psamma, and compare it with that of Solomon's seal and iris.

PLANTS WHICH FORM CORMS. Every crocus or gladiolus plant is reduced, during the winter, to a corm, which is a short, thick, erect, food-storing underground stem protected by brown scale leaves (cp. Fig. 117 B). This stem bears several buds; the uppermost of these will produce next year's flowering stem (Fig. 117 B, *b*.). Dissecting this bud we find that it consists of a short stem, bearing a few scale leaves, a few miniature foliage leaves, and a tiny flower (Fig. 117 C, *fl*.). For in this plant, as in many other perennials, the leaves and flowers which unfold in one season are formed during the preceding one.

Such is the hibernating plant, as it exists from early summer onwards. Growth sets in in late winter, numerous adventitious roots being formed from the base of the corm. Later, a few of the buds grow out into aerial shoots, unfolding their foliage leaves and flowers. While these foliage leaves are assimilating above ground, surplus food passes back into that portion of the stem from which both scale and foliage leaves arise, and the base of each such stem becomes swollen with stored food (cp. Fig. 117 A, D). It swells, buds develop in the axils of some of its leaves, its scale leaves turn brown and form a protective wrapping around it. The aerial portion of the shoot withers and falls off, leaving a scar. When all is finished, a new corm (or several, if some of the lateral buds have developed) is left with the previous year's corm as a dark, shrivelled, dying remnant beneath it. Since each new corm is formed above the old one, the plant tends to rise out of the ground. This is prevented by the formation of contractile roots, somewhat thick roots which are produced between the old and the new corms, and which, by their shrinkage, pull the new corm down.

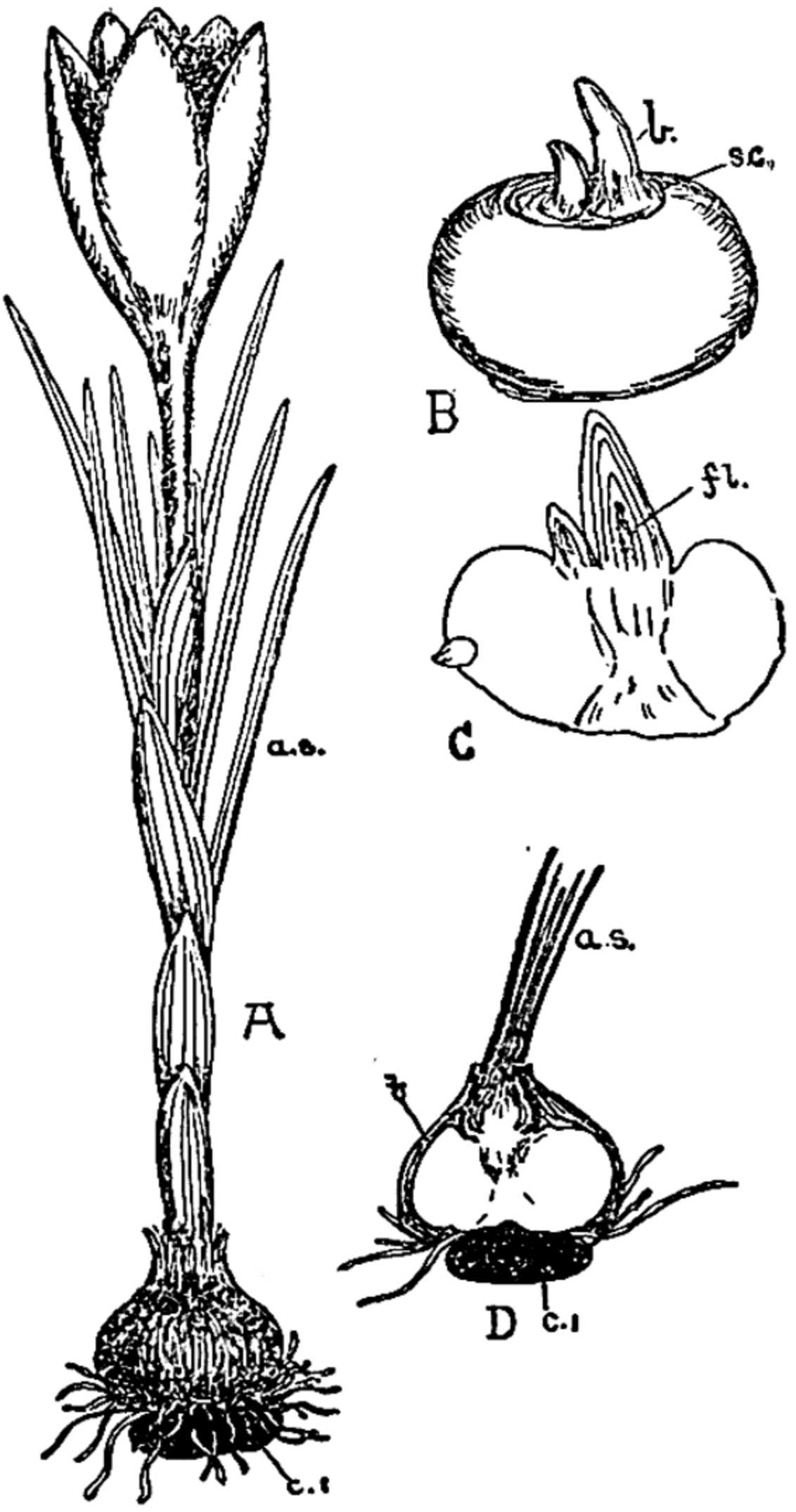


FIG. 117. THE CROCUS PLANT

A. Whole plant; observe, *c.1.*, the old corm; above it the present year's one; above this next year's corm is beginning to develop. Notice the scale leaves on the corm, also those on the aerial shoot (*a.s.*). Above these are the foliage leaves and flower. **B.** The resting corm in winter. **C.** The same in longitudinal section. *b.* = terminal bud of corm, *fl.* = flower in terminal bud. *sc.* = scar of scale leaf. **D.** Longitudinal section of base of plant **A.** *c.1* = old withered corm. (All natural size)

Exercises

Examine and sketch a crocus corm. Remove its leaves, one by one, and make a series of drawings which illustrate its structure. Examine also a crocus plant in flower, and another after flowering has ended. Carefully sketch both specimens.

Examine other corm-making plants, such as bulbous buttercup, gladiolus, cuckoo-pint, and montbretia. In the latter the swollen stem consists of several sections, one above the other, in place of the single swelling formed each year in crocus, &c.

Experiment 100. Test the crocus corm for carbohydrates, oils, and proteins, and ascertain the nature of the stored food.

THE PLANT WHICH MAKES TUBEROUS STEMS. A potato plant has small creamish flowers, which produce fruits and seeds in the autumn. The germination of the seed is epigeal, a typical dicotyledonous seedling being produced. Soon the young plant gives rise to lateral shoots of two kinds. Near the top of the stem these shoots become aerial stems bearing foliage leaves. Lower down, beginning in the axils of the cotyledons themselves, the lateral stems turn down into the ground, produce scale leaves only, and form structures like rhizomes. The tips of these underground stems are the food-storing organs of the plant (cp. Fig. 118 A). They swell as food passes into them, forming *tubers*—the potatoes of the dinner-table. Thus a tuber is the swollen end of an underground stem.

In the autumn all parts of the plant die away except these tubers. They remain in the ground, and form excellent perennating organs, being protected by a corky skin which is pierced by lenticels (Fig 118 B).

Exercise. The student should examine a potato, noticing the eyes (buds), the apical bud, and the scar which marks where the tuber became detached from the rhizome of which it is the swollen apex.

A potato plant thus has two methods of reproduction. It forms seeds, which germinate and give rise to seedling plants; it also forms tubers. These tubers can grow into new plants, producing adventitious roots and aerial shoots at the expense of their stored food (cp. p. 421).

We shall return to the consideration of this subject in a later

chapter (cp. Chapter XXXI). It is obvious that, in some ways, a new plant arising from a tuber has a better chance than one developed from a seed. It has a greater store of food to draw upon, and is already buried in the soil, where it lies protected

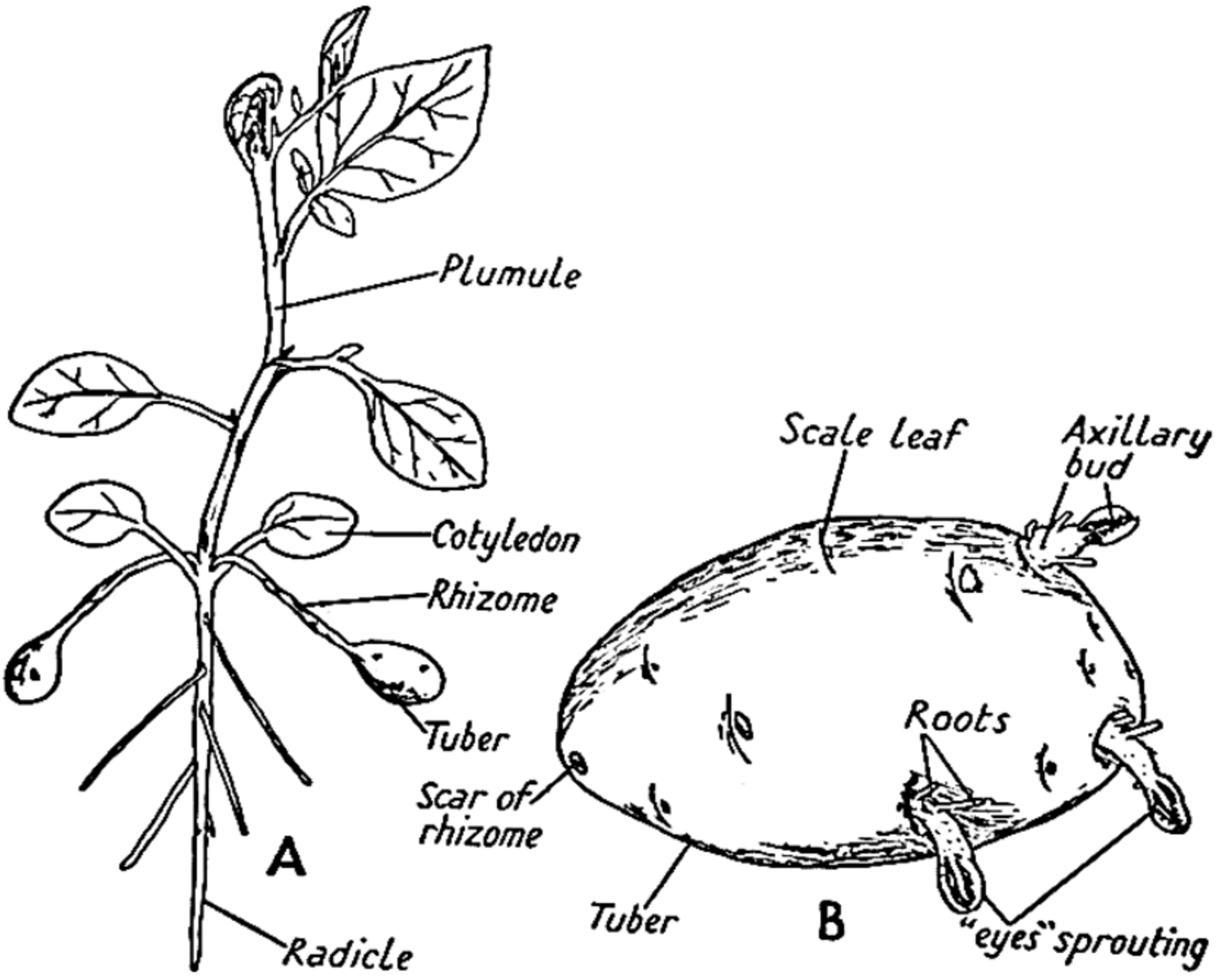


FIG. 118. THE POTATO TUBER. A. A seedling plant, showing the formation of the first tubers. B. A mature tuber beginning to grow

during the winter. But in nature it has no chance of being carried, as a seed may be, to 'fresh fields and pastures new'. It would inevitably grow in the old soil where its parent had grown, and would, moreover, have to meet the intense competition of all the other tubers close round it.

Exercise. Examine and sketch the tubers of Jerusalem artichoke, perennial sunflower, and the Chinese artichoke, and compare them with those of the potato.

THE PLANTS WHICH FORM BULBS. Bulbous plants are another group of perennials in which the hibernating structure contains a large store of reserve food. Fleshy rhizomes, corms, and tubers all have their foodstore in the stem; in bulbs it is found in food-storing scale leaves, a bulb being nothing but

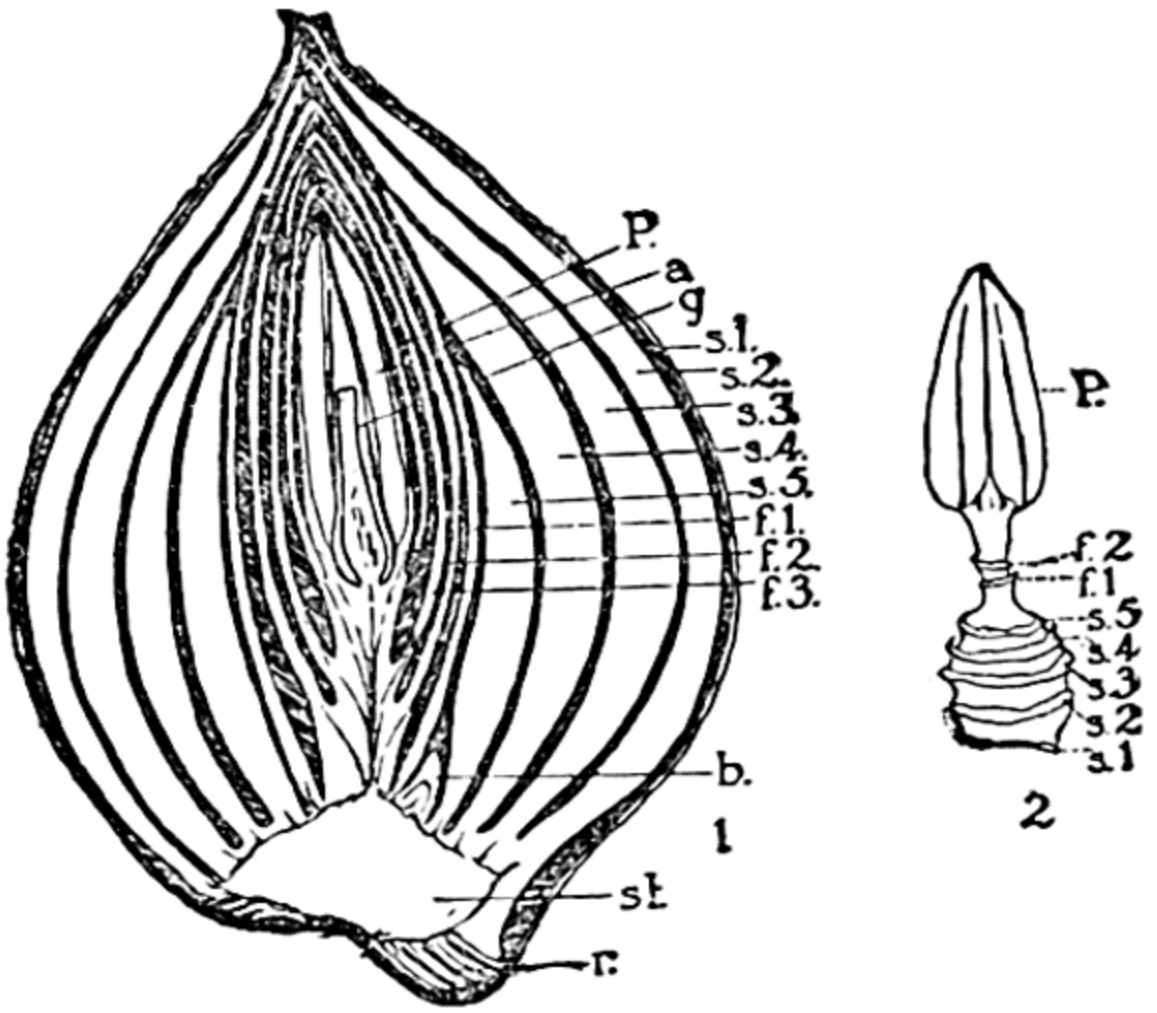


FIG. 119. THE STRUCTURE OF THE TULIP BULB

1. The bulb in longitudinal section. 2. The stem with scars of the leaves, which have been removed. *s.1, s.2, s.3, s.4, s.5.* Scale leaves. *f.1, f.2, f.3.* Foliage leaves. *P.* Perianth. *a.* Androecium. *g.* Gynoecium, of flower. *st.* Base of stem. *r.* Adventitious roots. *b.* Axillary bud which will become next year's bulb

a large bud. The tulip bulb, for example, consists of a flat disk-like stem, bearing the following structures:

A smooth, membranous scale leaf.
About four thick, fleshy, colourless food-storing scale leaves.
Three small foliage leaves. (Fig. 119, *f.1, f.2, f.3.*)
A terminal flower. (Fig. 119, *P.*)

Exercise. Dissect a tulip bulb, and sketch its various parts. Divide a second bulb longitudinally, and construct a longitudinal section.

Experiment 101. Test the scale leaves of the tulip bulb for various foods to ascertain the nature of their store.

The life-story of the tulip is very similar to those of the plants already described (e.g. crocus.) Adventitious roots grow rapidly from the base of the stem, the central bud elongates and forms an aerial shoot. Any food made by the foliage leaves in excess of the plant's immediate requirements passes back into the axillary buds on the underground portion of the stem. These buds form food-storing scales, foliage leaves, and even a flower; in short, each is a potential new bulb (cp. Fig. 119, *b*.).

All the mature parts of the old plant shrivel and die, the aerial shoots above ground, scale leaves, and older parts of the stem underground; finally one or more new bulbs are left in the ground, enclosed in the shrivelled remains of the parent bulb.

The new bulbs rest through the winter, and growth begins again.

Exercise. You are given specimens illustrating various stages in the life of the bluebell, a well-known British bulbous plant. Make a series of sketches, showing how the bulb is formed. In this plant the reserve food is stored in the bases of the ordinary foliage leaves, and not, as in the tulip, in specialized food-storing scales. The leaf-bases persist after the aerial parts of the leaf have decayed.

A SUMMARY. We have now reviewed very briefly the chief forms assumed by herbaceous perennials. A careful comparison of their diverse habits of growth shows that these plants generally hibernate underground or with some organs just above the surface of the soil, and that only their rapidly growing summer shoots are thrust up into the light and air. The earth is a good blanket. Frost does not penetrate it, the force of the wind is broken at its surface; hence plants buried in it, or growing near its surface, are less liable to destruction than those more exposed to the elements. We know how animals likewise seek its shelter (cp. p. 387).

In the woody perennials, with their large permanent overground shoot systems, there must be other methods of meeting frost, drought, and similar adverse conditions. Let us turn to the study of this group.

WOODY PERENNIALS

SHRUBS AND TREES. Although these plants differ greatly in size and in their detailed structure they have many features in common. Their stiff, branching stems are protected externally

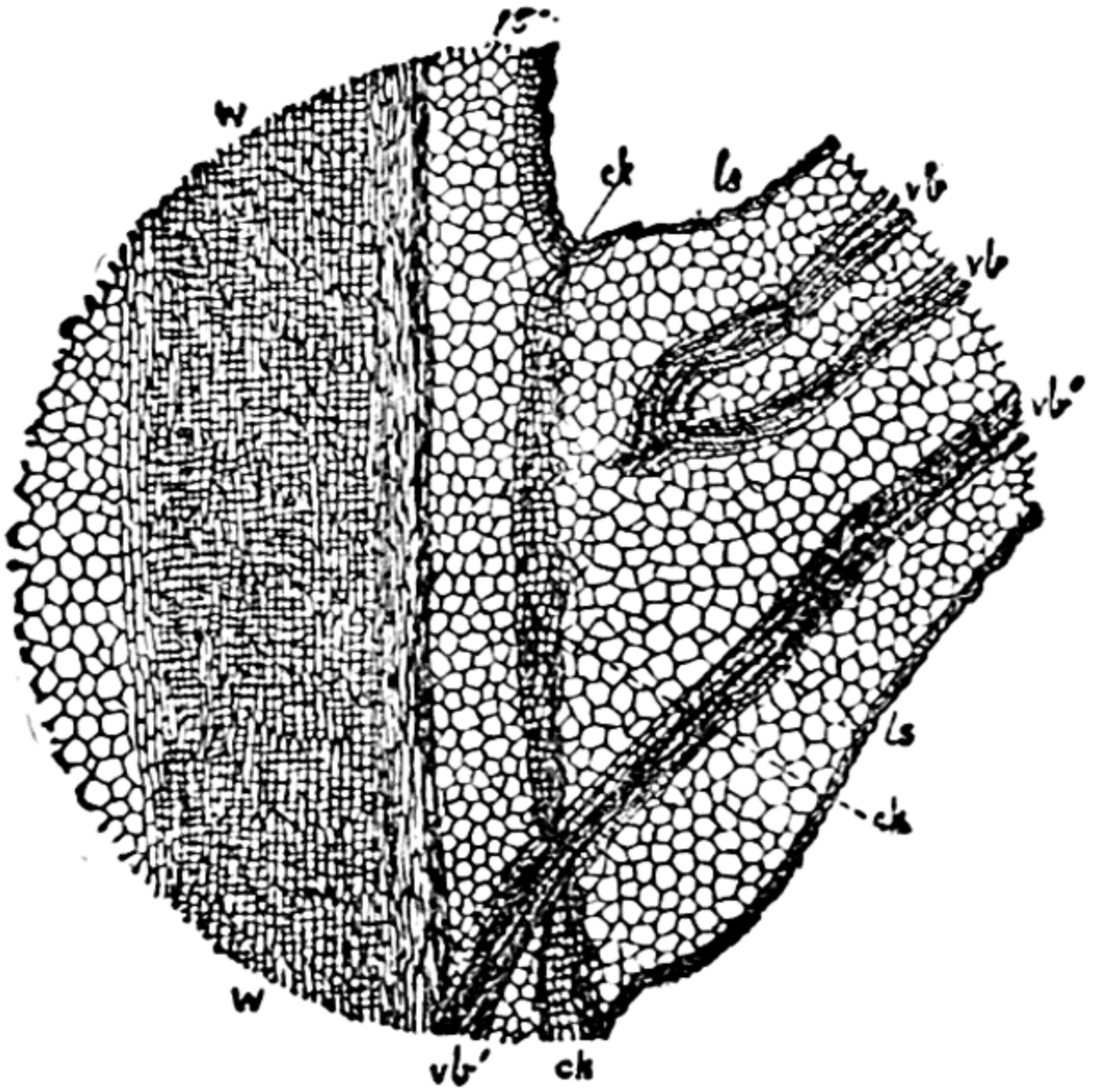


FIG. 120. The layer of cork cells formed at the base of a deciduous leaf in autumn. *w*. Wood of stem. *vb*, *vb*^{1}. Vascular bundles of leaf. *ls*. leaf base. *ck*. Cork cells

by a layer of cork, which is pierced by lenticels (cp. p. 274). The older stems have a characteristic bark, fissured, scaly, &c. On the younger twigs many scars are visible; in particular:

(*a*) Scars left by leaves of previous years.

(*b*) Scars left by flowers and fruits.

(*c*) Scars left by bud-scales of previous seasons (cp. Fig. 78).

They all have well-protected buds, the bud-scales developing cork, resin, or other waterproof substance.

In the temperate zones one of the most striking features of plant growth is the opening of the buds in spring, the fall of the leaves in autumn, most woody perennials of those regions being deciduous. Before the leaves of one season fall most of the new organs (leaves, flowers, &c.) which will be unfolded in the next season are already formed; they lie dormant and protected within terminal and axillary buds.

Exercises

Examine a horse-chestnut tree (*a*) in winter, (*b*) in spring and early summer.

Examine winter twigs of the horse-chestnut, and sketch a typical one (cp. Fig. 78). The large *leaf-scars* are in crossed pairs, and each shows about seven dots, which mark the broken ends of veins. There are buds (or branches) in the axils of these fallen leaves. The *bud-scale scars* resemble the leaf scars, but are very much smaller, and crowded together without internodes. They too occur in crossed pairs, and have tiny dormant buds in their axils. *Inflorescence scars* may also be visible on the twig. Each scar is large and round; it ends the growth of the stem which bore it. Such a stem elongates from the axillary buds just below the inflorescence (sympodial growth) and hence it forks after an inflorescence has been formed.

Examine and make sketches illustrating the structure of the large terminal bud of a horse-chestnut. It is protected by many brown, sticky scale leaves, arranged on the stem in crossed pairs. Within these are young foliage leaves, covered in a tangle of white hairs. The axis of the bud may end either in a growing point or in an inflorescence. Study the opening of these buds, both on the tree and on twigs kept in water. Sketch the opening buds. (Observe the negative geotropism of the young shoots and of the inflorescence axis.)

The bud-scales separate, moving outwards and downwards; the foliage leaves enlarge; the internodes between them grow longer, this continuing until they have reached their full length. The leaves lose their covering of hairs and turn so that their surfaces face the light. Meanwhile the scale leaves are shed, leaving scars on the shoot. We see that the whole length of stem between ring markings and terminal bud develops one season from structures laid down at the apex in the preceding year.

Examine and sketch the twigs and buds of other familiar trees and shrubs, e.g. beech, sycamore, elm, hawthorn, rose, &c.

PREPARATION FOR WINTER IN TREES AND SHRUBS. When the season's growth in length is finished, and the tree has unfolded its canopy of leaves, it assimilates rapidly, nourishing the parts which are in process of development (seeds, growing points, &c.), and in addition laying up a store of surplus food in its woody parts. As autumn approaches, it prepares for its winter rest. A thin *absciss layer* is formed across each leaf-stalk, with a protective layer of cork below (cp. Fig. 120, *ck*). The leaf, cut off from the rest of the plant, and particularly from the supply of water, withers, dies, and is blown away by the next high wind. A scar is left, protected by cork, the break occuring at the absciss layer. The lenticels also become filled with loose, powdery cork cells as winter approaches. Respiration drops to a minimum; assimilation, absorption by the roots, transpiration, &c., all cease; the whole tree (or shrub) relapses into a dormant condition, in which state it remains until the spring rouses it once more to activity.

EVERGREENS. In some trees and shrubs the leaves last for several years before they are shed; hence such plants are evergreen. Their leaves are usually small, tough, and leathery, being protected by a waterproof epidermis, often more than one cell thick. This enables them to live unharmed through winter conditions.

THORNS, SPINES, AND PRICKLES. Many plants form sharp outgrowths which make the whole plant 'prickly'; in England we have many prickly shrubs, holly, gorse, hawthorn, rose, blackberry, and butcher's broom being among the commonest. These outgrowths may represent modified stems (hawthorn, gorse), leaves or parts of leaves (barberry and gorse), or they may be merely stiff, sharp-pointed hairs (holly, rose, goosegrass, blackberry (cp. 121 A)). All such structures are probably useful as defences against animals (cp. p. 368).

Exercise. Examine and sketch any evergreens and any spiny plants obtainable. Ask yourself in every case the nature of the spines; if a *stem*, it arises in a leaf axil, if a *leaf*, it has a bud in its axil. *Prickles* occur irregularly on both leaves and stems.

CLIMBING PLANTS

Before we finish our survey of the forms of plants we must look at the scramblers and climbers. Plants growing close to the soil obtain some shelter from the elements, but are in

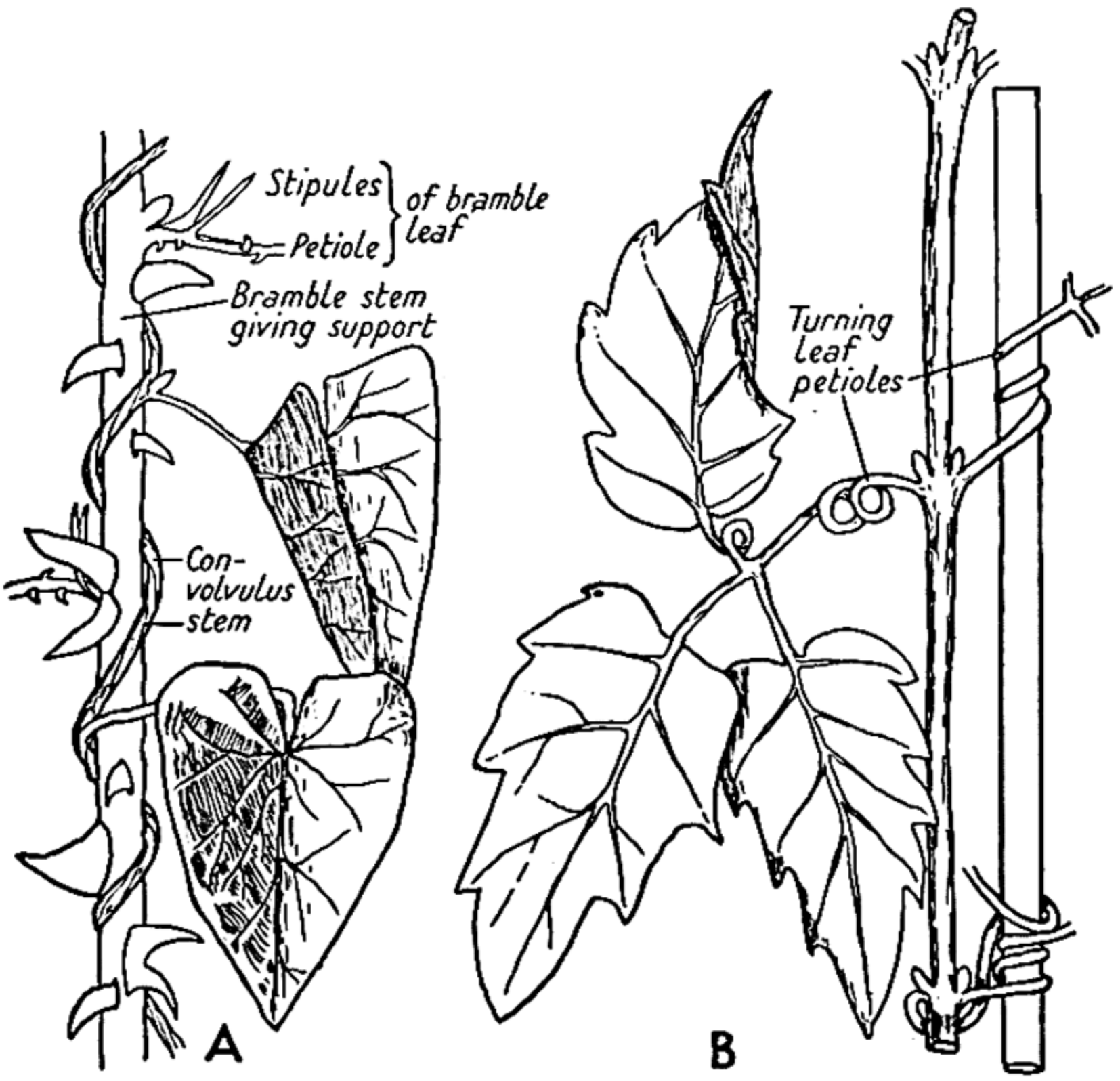


FIG. 121. TWINING PLANTS. A. Convolvulus climbing on a bramble plant, itself a climber. B. Clematis, which twines its leaf-petiole round the support

danger of being overshadowed by their taller competitors. Woody perennials build up solid, massive stems by which they spread out their leaves to the light and air. Climbing plants obtain these necessities in another way; the chief advantage of the climbing habit would seem to be that it enables a plant

to reach the light without having to build up a strong stem. The stems of climbers are usually slender, with long internodes, and quite unable to support their own weight.

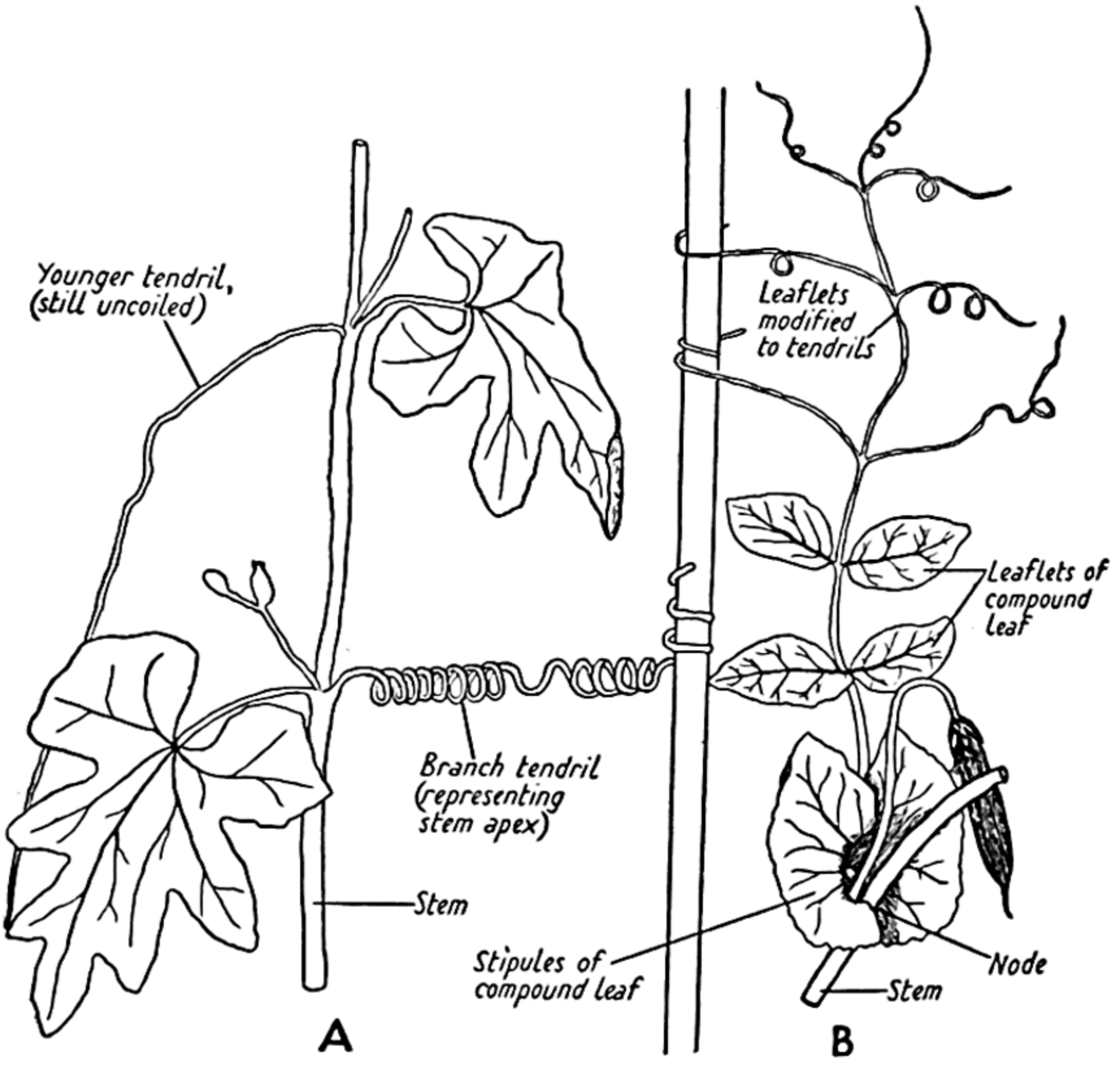


FIG. 122. PLANTS CLIMBING BY TENDRILS. **A.** White bryony with stem tendrils. **B.** Garden pea with leaflet tendrils

TWINING PLANTS twist their stems (hop, black bryony) or their leaf-petioles (clematis, nasturtium) round a support. TENDRIL CLIMBERS form definite climbing organs, either modified leaflets (peas, vetch), or modified branches (white bryony). SCRAMBLERS (rose, blackberry, goosegrass) climb by their prickles; ROOT CLIMBERS (ivy) by adventitious roots.

Exercise. Make a collection of climbers, examine them, and determine how they climb.

QUESTIONS ON CHAPTER XXVIII

1. Explain what you understand by an annual, a biennial, and a perennial herb. Give one named example of each group.

2. In what parts of plants may food be stored? Mention definite examples in each case. State the nature of the principal stored material. Explain how such food resources are rendered available for use by the plant. (Ox.L.)

3. Describe by means of labelled drawings the yearly cycle of the potato or any other named plant which produces bulbs, corms, or tubers. (C.L.)

4. Give an account of the structure of the young stem in a typical dicotyledon, and describe as fully as you can the changes that take place as secondary thickening proceeds. (L.G.S.)

5. Describe and compare the general habit and manner of growth of a tree and of a herbaceous plant. (J.M.B.)

6. Give an account of the different ways in which plants pass the winter. (Ox. & C.)

7. Explain as fully as you can why it is unwise to remove the leaves of daffodils, crocuses, and other similar early-flowering plants directly flowering is over.

8. A tulip bulb is often described as a large bud. Justify this statement by comparing a tulip bulb with a horse-chestnut bud, when both are in the dormant condition.

9. Describe the structure of the stem of a typical flowering plant, and give an account of two examples of stems modified to perform special functions. (L.G.S.)

10. Make labelled drawings to illustrate the essential features of plants which propagate vegetatively by means of (*a*) runners, (*b*) suckers, (*c*) rhizomes. Name the examples you select to illustrate your answers. (C.L.)

11. The age of a twig or branch of a tree may be determined by certain external characters or by an examination of its annual rings. Explain these two methods, and illustrate each method by a sketch. (J.M.B.)

12. Make a drawing of a shoot of any flowering plant showing stem, leaves, terminal and axillary buds. Explain the circumstances in which axillary buds grow out. (Ox. & C.)

13. Describe two climbing plants and two climbing animals. In each case describe how the organism climbs, and the advantage to it of the climbing habit.

CHAPTER XXIX

GROWTH IN ANIMALS

ANIMAL AND PLANT GROWTH. In a former chapter (cp. p. 358) we learned that plants usually retain the power to grow all through life, adding to their bodies by division of the embryonic cells at the apical growing points.

There is no such continuous growth in animals. In early life all parts of the body grow; the larva becomes an adult insect, the tadpole a frog, the kitten a cat. Soon the animal is mature, and by no known process can we add another cubit to its stature. Yet, although the size of the body as a whole does not increase, the power to grow, i.e. to renew worn-out tissues, is not lost. Crabs, lobsters, &c., cast their shells, snakes their skins, birds their feathers, mammals their hairs, and in all such cases these structures are renewed. Even in old age, the hair and outer epidermis of human beings are constantly being cast off and re-formed, the nails continue to grow, and many similar renewals continue so long as life lasts. These well-known things serve to bring clearly before us the fact that, when growth in the animal body is finished, it still retains the power of renewing its structure.

Some animals, like most plants, have great powers of *regenerating* injured parts (cp. exp. 82). If certain worms are cut in two, each half may grow into a whole animal. The common lizard casts its tail, if this is held by an enemy, and grows a new one from the stump. The stick insect, so often kept in the laboratory, will, if it loses a leg, grow a new one in a surprisingly short time. The lower we go in the scale of animal life, the greater on the whole is this power of regeneration, but all possess it in some degree. Even in a human being, though he cannot get another limb, yet severe cuts will heal, broken bones unite, even injured nerve-endings may be regenerated.

RATE OF GROWTH. Young animals, like young plants, often grow at an astonishing rate; in the thirty days of its greedy larval existence the 'silkworm' increases its weight more than a hundredfold.

Experiment 102. Weigh a batch of ten recently hatched caterpillars of the cabbage white or some other butterfly. Weigh them again after a week, and again at the end of the second week. Draw a graph showing the rate of growth.

A newly hatched thrush measures about 1¾ inches from beak to tail; it is ready to fly 12 days later, and is then about 4 inches long. It has more than doubled its size and weight in 12 days. A human baby usually weighs about 7½ lb. at birth; this weight is doubled in about 20 weeks, is trebled by the end of the first year. The increase is still rapid in the second year, but it gradually falls off, and continues at a fairly steady rate until, at about the twenty-first year, growth is ended.

The rates of growth of the various parts of the body are different at different times, so that the proportions of the body vary considerably as development proceeds. We all know how 'leggy' is a young puppy. The head of a baby forms about one-quarter of the whole length of the body; that of an adult only one-seventh of that length.

SIZE. Animals, even those belonging to the same group, vary tremendously in size. Mammals range from the elephant and the whale to the tiny harvest mouse:

'Two of them, in a scale, weigh down just one copper halfpenny, which is about the third of an ounce avoirdupois.' (White of Selborne.)

We cannot say what causes this great diversity, but it is obvious that size is, to some extent, limited by external conditions. Mammals are warm-blooded creatures; if too small, their surface is so large in comparison with their size that they lose energy by surface radiation more rapidly than they can replace it. A mouse must already eat half its own weight every day, in order to make good this loss, while a man only requires to eat one-fiftieth of his weight. It follows that a warm-blooded mammal much smaller than a mouse could hardly exist; to replace heat lost would demand more food than it could eat in the time available.

Very large size, on the other hand, brings other disadvantages. Firstly, there is the difficulty of getting rid of the heat

formed in the body, since the surface is small compared with the volume. Large bodies are also difficult to conceal and difficult to support, unless buoyed up by water; hence the largest mammals (whales) are found in the sea. In a land vertebrate the weight is supported on legs and, for this reason alone, the body cannot grow in size indefinitely. Enormous quadrupeds require legs so massive that they are almost too heavy to move. It seems possible that the gigantic reptiles of a past age became extinct because they had over-stepped the upper margin of safety in this respect.

THE SIZE OF BIRDS is also limited by their way of life. We find that heavy ones, like ostriches, cassowaries, and kiwis, have lost the power of flight. To raise and sustain so heavy an object in the air would be a most difficult task. It is interesting in this connexion to inquire how much 'fuel' birds need when they fly. Experiments have shown that golden plover travel from Nova Scotia to South America, a distance of 2,400 miles over open ocean, in 48 hours, and that during the journey they lose 2 oz. of fat, i.e. these particular birds use 2 oz. of fat, a very concentrated form of fuel, for covering a distance of 2,400 miles!

THE SIZE OF INSECTS. A tiny flying creature incurs different risks. It is at the mercy of the elements, and may be blown far afield, possibly far out to sea, especially during a gale Here is a graphic description of a disaster of this kind, which overtook some cabbage white butterflies on the Norfolk coast on 4 June 1931:

'I suddenly caught sight of what seemed to be a snow-storm drifting along the hills before the east wind. As the snow-flakes approached they resolved themselves into large white cabbage butterflies (Pieris brassicae). At times the whole sky was full of them. . . . With my glasses I could detect clouds of these butterflies drifting across the sea on a wide front. Pursued by various birds, and buffeted by the wind, they fell to the ground bruised and broken.' (Turner, *Bird Watching at Scolt Head.*)

It has been suggested that the size of insects is also limited by their method of breathing (cp. p. 291). Oxygen reaches

their internal tissues largely by gaseous diffusion, and, this being a slow method of transport, it could not supply cells very far from the surface.

SIZE REGULATED BY NATURAL SELECTION. We have said enough to show that there are certain upper and lower limits set by external conditions to the size to which animals can grow. Those that transcend these limits run great risk of destruction, such 'outsizes' often perishing when the struggle for existence becomes severe. Hence there is a continual process of *natural selection*, by which only those whose size is suitable to the conditions are left to carry on the race.

GROWTH AND EXTERNAL CONDITIONS. Animals, like plants, can only grow if given the right environment. Water, food, air, and the right range of temperature are necessary for all living things (cp. p. 358).

Experiment 103. Divide some frog's spawn, water-snail's eggs, or other similar material into two batches; keep the one batch in a warm laboratory, the other under similar conditions, but in an unheated room. Make notes of times of hatching, rate of growth, &c. The former group develops much more rapidly.

If a bird deserts its nest the embryo birds inside the eggs die from cold. Animals are, perhaps, more easily killed by adverse conditions than are plants. We are gradually realizing the importance of a healthy environment to the growth of children; hence the agitation for slum clearance, for a pure milk supply, for holiday camps and open-air games, for sunny well-ventilated homes and classrooms, for good food and proper medical supervision; in short, for such conditions as will ensure healthy growth and give us a nation composed largely of individuals with an A1 physique.

PREPARATION FOR WINTER. HIBERNATION. In a country like Great Britain the effects of temperature change on animal life are very noticeable. Cold usually brings all growth to an end. Many creatures die before winter sets in, leaving eggs which are able to withstand low temperatures. Of humble-bees and wasps all die except the young queens; these hibernate in some burrow or crevice, and each can start a new

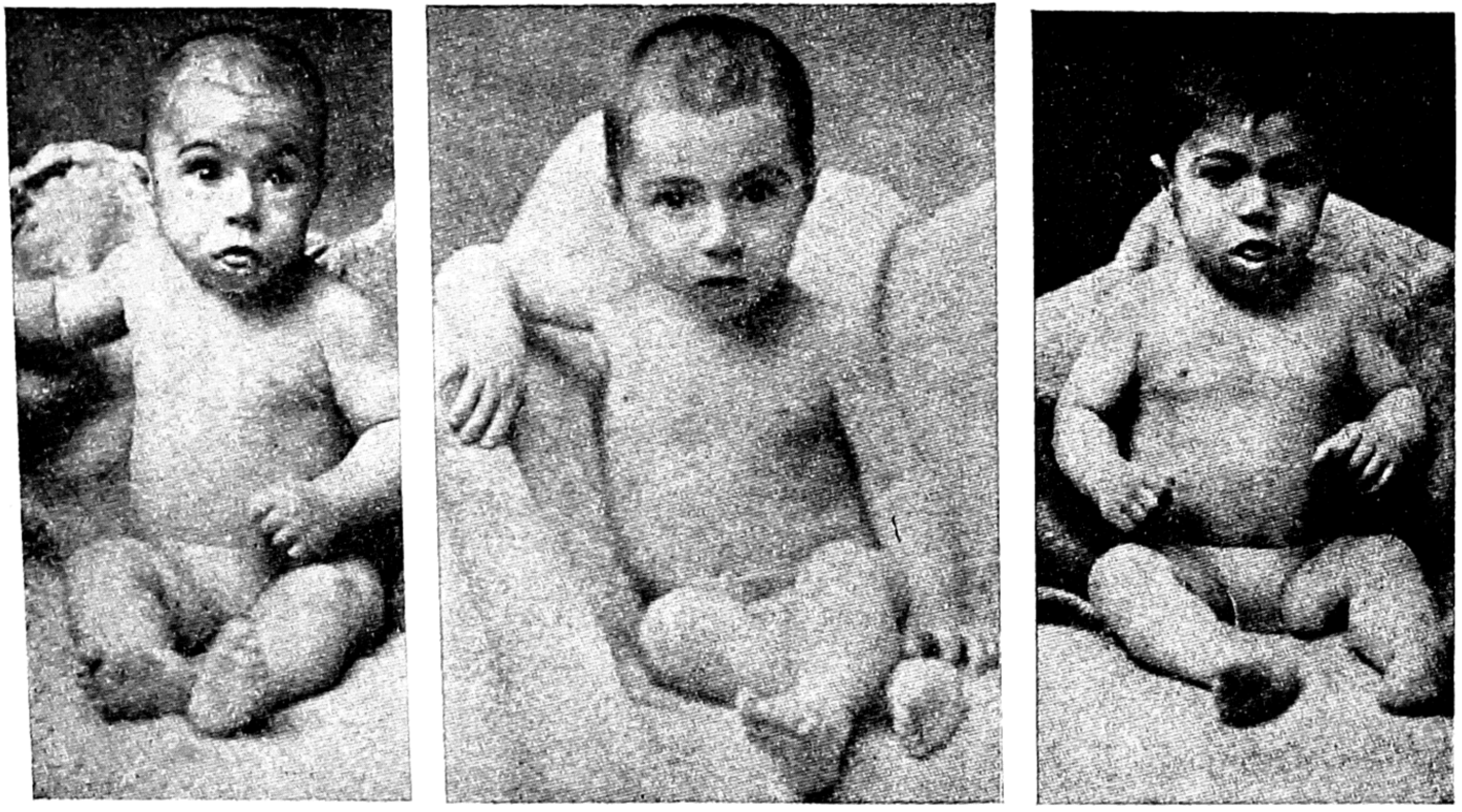


FIG. 123. EFFECTS OF LACK OF THYROID ON HUMAN DEVELOPMENT. On left, child with stunted growth and mental deficiency resulting from maldevelopment of thyroid gland. In centre, the same child after some months' treatment with sheep's thyroid. On right, the same child a year later. The symptoms have returned, its parents having refused to continue treatment. (Photographs by Dr. Max G. Schlapp)

colony in the following year. The beehive witnesses the 'massacre of the drones' as winter approaches. Many creatures disappear underground; earthworms burrow down into layers of soil beyond the reach of frost, ants retreat into the lowest part of the nest. Many a chrysalis lies buried in the ground. The land-snail closes the opening of its shell by a thin but porous plate (the epiphragm), and retires to some sheltered crevice to live through the winter in a state of torpor. So deeply engrained is this habit that even when kept indoors snails hibernate completely, although they are warm and well supplied with food.

Even among vertebrate animals similar preparations for winter are to be observed. Toads, frogs, and newts seek safe hiding-places among thick moss, in the uninhabited burrows of other animals, under decaying water-weed, or buried deep in the muddy bank of a pond; indeed, except for the warm-blooded creatures, mammals and birds, who can keep up their body-temperature in spite of the surrounding cold, few animals are to be seen during the winter months. Even these groups contain many birds that migrate to warmer climes, while certain mammals hibernate through the winter. Dormice, squirrels, &c., sleep lightly, waking up during any warmer spell; hedgehogs, bats, &c., sleep very deeply the whole winter through. The hedgehog rolls itself into a tight ball, and buries itself among dead leaves in some sheltered hole. Bats retire to some church tower, old barn, hollow tree, or cave, where they hang, head downwards and enveloped in their wings, till spring returns.

In all these dormant creatures life is at a very low ebb. They store up food during the summer which keeps them just alive during the winter; respiration is at a minimum; in vertebrates the heart beats slowly and faintly; there is the minimum of activity and the minimum of waste, and the fat or other food stored during the summer is enough to supply these minimum needs.

CHEMICAL FACTORS INFLUENCING GROWTH. A recent discovery of great interest is that there are certain chemical substances, *hormones*, which exert a profound influence on growth (cp.

p. 225). One of these substances is *thyroxin*, a compound which can now be manufactured in a chemical laboratory. Vertebrate animals secrete this substance in the *thryoid gland* of the neck. It is essential to healthy growth; a baby whose thyroid is not active develops quite abnormally into a repulsive idiot (a cretin). Fortunately this condition can be remedied by the administration of pills containing thyroxin (cp. Fig. 123).



FIG. 124. Showing how the secretion of the thyroid gland affects growth. Both tadpoles are of the same age. The one on the right (the control) has metamorphosed normally. The one on the left had its thyroid removed early. It has not turned into a frog but has grown into an abnormally large tadpole

The change from tadpole to frog (cp. p. 321) also depends on a supply of thyroxin. The thyroid gland can easily be removed from newly hatched tadpoles, and such animals will continue to grow, but without undergoing metamorphosis (cp. Fig. 124). Conversely, if thyroxin is given in excess, the change takes place prematurely, and very miniature frogs are produced. The substance apparently affects the rate of growth, accelerating this rate in some tissues (e.g. limb buds, &c.) and inhibiting it in others (e.g. gills). In this respect its action is like that of *auxin* in plants (cp. p. 358).

In human beings it has recently been shown that size is to some extent regulated by the secretion of another gland, the *pituitary*, which lies in the skull under the base of the brain. Excess of pituitary secretion in early childhood leads to increased growth, especially in the long bones of the limbs, so that the child becomes a giant; diminished secretion, on the other hand, leads to the production of a certain type of dwarf. *Vitamins* (cp. p. 51) also exert a great influence on growth, lack of any of these substances profoundly altering the whole development of the animal. A bandy-legged, rickety condition, for example, is one result of the lack of vitamin D.

ANIMAL GROWTH. CONCLUSION. This review of some of the more striking facts about growth in animals shows us how complicated are the processes at work, and how little we know about them, particularly about the way in which the growth of different parts of the body is co-ordinated. Much remains to be discovered; biologists have so far only explored the fringes of this great subject (cp. p. 346).

THE GROWTH AND DEVELOPMENT OF THE INDIVIDUAL ANIMAL BODY

We know (cp. p. 319) that the frog starts life from a single cell. With a few exceptions, most animals start in a similar manner (cp. p. 433). Let us see how this egg-cell develops into the adult animal.

CLEAVAGE OF THE EGG. Development begins with the division of the egg-cell into two, four, eight, sixteen cells, and so on; usually there is no increase in size during this first phase of development; the protoplasm is being subdivided into smaller units, each presided over by its own nucleus (cp. Fig. 125, 1–5). These units are all undifferentiated embryonic cells, like the egg-cell which produced them. Indeed it is often possible at the two- or four-celled stage to separate them by delicate dissection, when they are found to be so alike that, in many cases, e.g. frog, each cell will grow into a whole animal.

It seems possible that 'identical' human twins, who are always of the same sex and more like each other than ordinary brothers and sisters, are produced in this way, by separation of the two cells resulting from the first division of the human egg-cell. This cell is only one-tenth of a millimetre in diameter.

THE BLASTULA. Cell-divisions continue until a hollow sphere is formed (cp. Fig. 125, 7). This represents a stage through which most multicellular animals pass in the course of development, the sphere being called a blastula. In the development of the frog (cp. Fig. 98) the blastula stage is reached about 24 hours after the beginning of cell-division.

THE GASTRULA. During the next phase of development the blastula is transformed into a two-layered and often cup-shaped structure, the gastrula. This transformation is brought

about in various ways, one being by the ingrowth of one half of the blastula wall against the other half, a process known as invagination (cp. Fig. 125, 9–11). The cavity of the sphere is obliterated and a new central cavity is formed. The cells of the embryo are no longer exactly similar; no longer can one of them, if separated from the rest, grow into a whole animal. Very early in the life-history differentiation begins, and the cells are so marshalled that each will give rise to certain limited and well-defined parts of the whole body.

COELENTERATES. The animals belonging to this group, such as Hydra, jelly-fish, sea-anemones, and corals, never pass beyond a gastrula-like stage of development. They retain this form with comparatively unimportant modifications, such as the formation of tentacles round the mouth, &c., all through life. In Hydra, for example, the cells of the gastrula become differentiated into the various elements of the ectoderm and endoderm, while the cavity of the gastrula represents the gut cavity of the mature animal (cp. Fig. 31).

THE THREE-LAYERED STAGE. GROWTH AND DIFFERENTIATION. In all the higher animals the gastrula stage is a temporary one, and is succeeded by a far more elaborate three-layered structure, in which the chief organs of the adult, nervous, circulatory, digestive, excretory, &c., begin to be mapped out. Cells are still dividing, here more rapidly, there more slowly; foldings of all kinds occur, and gradually a rough mould of the future organism is formed. Its shape alters continually, and new organs constantly emerge. The rudiments of the various organs consist at first of undifferentiated cells, but these become more and more specialized as development proceeds (cp. Fig. 98); the higher the animal, the greater is this specialization. As the formation of tissues proceeds growth slows down, for this takes place chiefly in embryonic cells. Power to grow is one of the capacities that is sacrificed for specialization; another power lost is the ability for such cells to exist independently.

There is a close parallel here between the development of an animal body and that of a human society. As civilization advances, every man and woman becomes more and more of a specialist; each

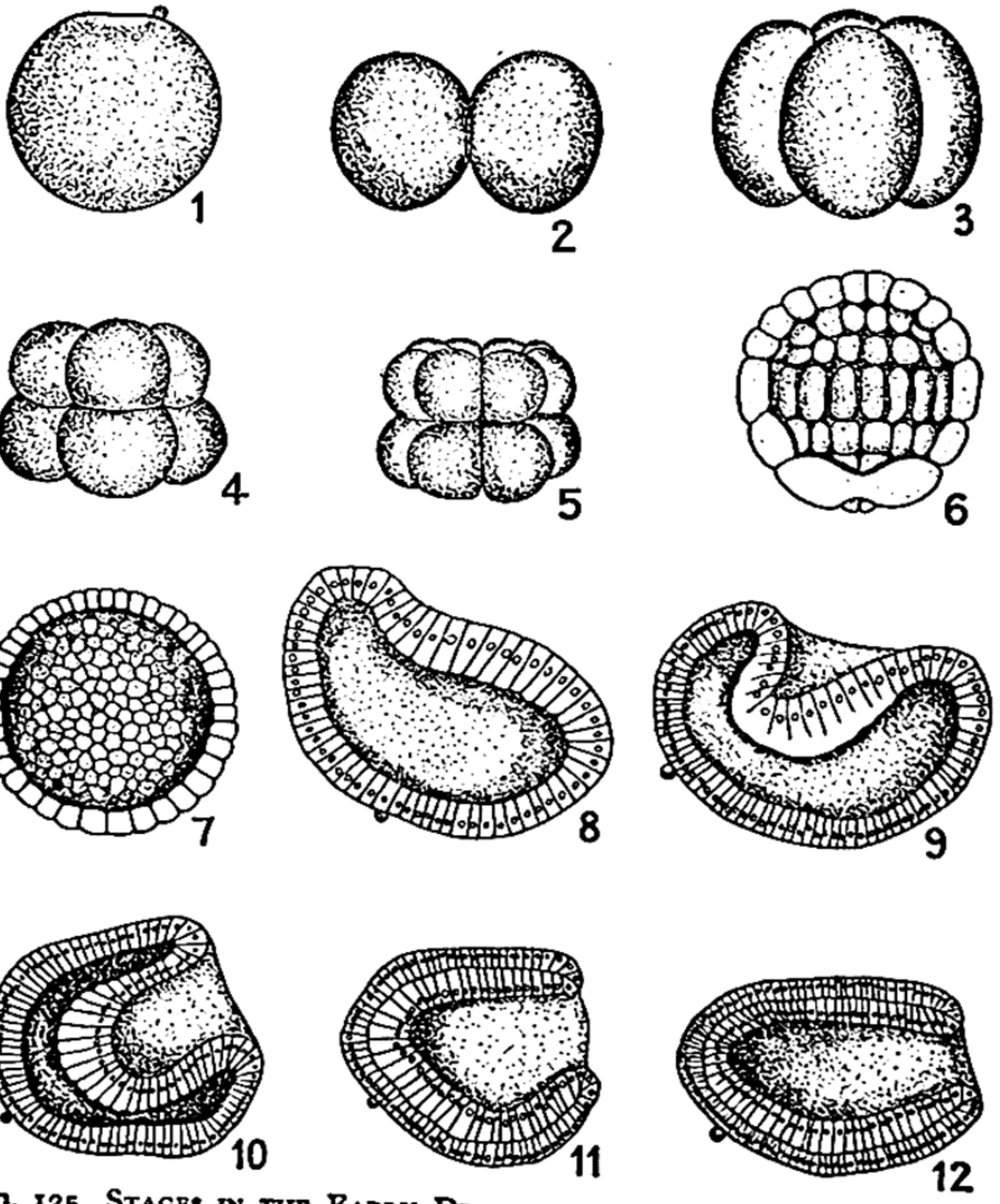


FIG. 125. STAGES IN THE EARLY DEVELOPMENT OF AN ANIMAL. 1. Egg-cell. 2–5. Divisions of the egg-cell. 6–7. Blastula. 8–10. Formation of two-layered embryo by ingrowth (invagination). 11–12. Gastrula

member of the group gains increased skill at his own job, the whole corporate life reaches a higher level of efficiency—a level quite unattainable by one man working alone. Similarly, the individual body progresses from simplicity to complexity, and the higher the organism, the greater is this complexity.

GROWTH AND METAMORPHOSIS

Some animals, in the course of their individual lives, pass through two separate and independent phases, so unlike each other that we say they undergo a *complete metamorphosis*, or change of form. Who, seeing the tadpole swimming actively in a pond, could suspect that it was a larval frog? Or who would connect the caterpillar with its butterfly, without previous knowledge of the growth of these animals? Yet we know that a similar metamorphosis occurs during the growth of many animals. Non-biologists are perhaps most familiar with it among the insects.

INSECT GROWTH, METAMORPHOSIS, AND ECDYSIS. Among insects indirect development is very usual. There are a few which undergo no obvious change, the newly hatched young being miniatures of the adults (e.g. silver-fish).

In others (e.g. locusts, stick insects, cockroaches, earwigs, &c.), the change of form during growth is very slight. A young *cockroach* just escaped from the egg-case (cp. Fig. 159) is very like its parents except that it has no wings, and in many cockroaches these never develop, but remain vestigial (cp. p. 157).

The difference between the young animal (nymph) and the mature insect is more striking in dragon-flies, may-flies, and related forms. The aquatic larva of the *dragon-fly* is something like the adult animal, but has no wings. These develop gradually, becoming visible as wing-pads after the second or third moult. From that time on they increase in size all through the long larval life. The nymph then comes out of the water to pupate (cp. Fig. 97). The winged insect which finally casts off the pupal skin uses its tracheae for air-breathing and its wings for locomotion.

The metamorphosis of the highest insects—flies, bees, ants, butterflies, moths, &c.—is still more complete. We have

studied it already in the *mosquito* (cp. Fig. 96); the life-histories of the butterfly, the ant, and the bee are told in Chapter XXXVI. In all these creatures the whole form of the larva ('caterpillar', 'grub', 'maggot') is different from that of the mature insect. It has no compound eyes, its mouth parts are different, it has no wings, and so on. In some groups (e.g. the 'maggots' of flies) it is even limbless and has only a very ill-defined head (cp. Fig. 126).

During metamorphosis these creatures all pass through an almost motionless stage known as the pupa or chrysalis. The winged insect that emerges (imago) is mature, and there is no further growth.

GROWTH AND ECDYSIS. The growth of insects is further complicated by the presence of a hard, lifeless, inextensible exoskeleton (cp. 402). This difficulty is overcome by that periodic *ecdysis* or casting-off of the skeleton which is characteristic of the whole arthropod group (cp. pp. 157, 312, 315). The number of such moults varies greatly in different forms: they are always most frequent in young animals. 'These periodic moultings during adolescence are very expensive and hazardous' (J. A. Thomson), nevertheless this method of growth is found right through the *phylum*. Let us review its occurrence in the insects we have studied.

The cockroach casts its cuticle seven times before, at five years old, it is mature. If wings appear, they come after the last moult. Dragon-fly nymphs moult from ten to fifteen times, the first occasion being some two minutes after they hatch out from the egg. When they leave the water there is one more moult, the nymph 'case' being split and cast off by the emerging winged insect. Mosquito and gnat larvae usually moult three times, at the third moult being transformed into a pupa. This pupal skin is cast off (fourth moult) as the fully grown winged insect emerges (cp. Figs. 96, 97).

The lives of other insects are given on pp. 312, 315, and 489–95. There is periodic ecdysis in them all. Let us end this study of insect growth by reviewing the life-history of a very common insect.

THE HOUSE-FLY. This ubiquitous insect (there are several very common species) is two-winged and aerial. It feeds largely on liquid food; to ingest solids it must first pour saliva over them and bring them into solution (cp. p. 141).

The female deposits her eggs in moist and decaying organic matter—for example in manure-heaps, a favourite haunt—and here the larval life is spent. It is these unhygienic customs that make flies so dangerous. Their number would be kept down if no suitable breeding-places were available.

About one hundred small, white, cigar-shaped eggs are laid. Within a short time—it may be only twelve hours if the temperature

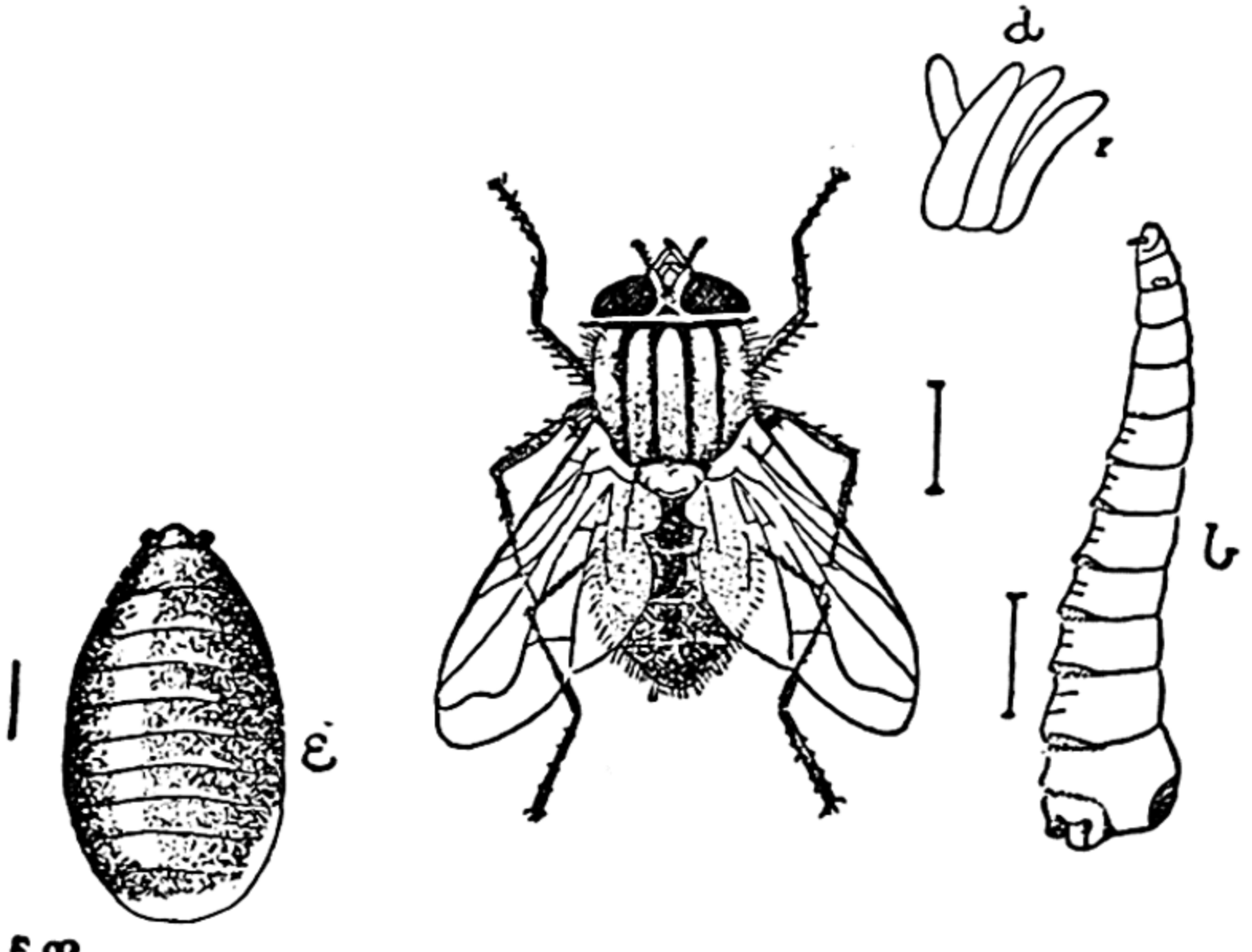


FIG. 126. THE DEVELOPMENT OF THE COMMON HOUSE-FLY. *d*. Eggs (much magnified). *b*. Larva. *e*. Pupa. (From Theobald)

is favourable—tiny, soft, white, legless 'maggots' emerge (Fig. 126 *b*). They have segmented bodies, with a small head at the pointed end, and twelve visible segments. On the last seven (6–12) are spines which function instead of legs. Two pairs of spiracles open on the surface, one pair on the second segment, the other on the last one.

The larva moults twice, each time increasing in size, and then moves away from the light to pupate (cp. Fig. 126 *e*). It does this inside its larval skin, which shrinks and becomes an oval, brownish, shell-like structure, within which metamorphosis occurs. A few days later (the time depends on the temperature), the full-grown fly is ready to emerge. The cuticle is split for the last time, the fly breaking it open at one end.

The whole development, from egg to a new batch of eggs, may only occupy nine or ten days.

Exercises

Collect the eggs or caterpillars (larvae) of any British insects, especially of butterflies or moths, and study their development.

Purchase some silkworm eggs and study their growth and development.

Revise the story of the lives of the frog, dragon-fly, and mosquito, told in Chapter XXV.

GROWTH AND MIGRATION

Another series of very interesting life-stories is that in which growth is intimately linked with migration. Born in one environment, the young animal travels far afield to complete its development in quite different surroundings, this journey being a constant and apparently necessary feature of its growth to maturity.

THE LIFE-HISTORY OF THE SALMON. In autumn and winter female salmon lay their eggs on gravelly beds in the upper reaches of clear rivers. The male pours his fertilizing fluid over them (cp. p. 431) and the eggs are then covered with gravel by the female. When the egg hatches, a tiny larva emerges, which is at first encumbered by a large swelling containing 'yolk', i.e. food stored in the egg-cell for use during the early stages of development (cp. Fig. 163). This store is soon absorbed, and the little fish, now about six weeks old and an inch long, begins to find its own food.

Growth continues slowly and steadily. The young creatures are about 4 inches long at the end of their first year, being now called *parr* by fishermen. When their second birthday draws near they are about 8 inches long. Soon they become silver-coloured (the fishermen now call them *smolts*), and begin to make their way out to sea. Here food is more plentiful than in the river; they feed greedily on herring and other fish and grow rapidly, until finally, either as *grilse* (young salmon about 3½ half years old) or as *fully mature salmon*, they make their way up the river once more, to lay eggs in their turn. This egg-laying so exhausts them that they often fall victims to

one of their numerous enemies. Many fish, therefore, only spawn once. Others succeed in making their way back to sea, whence they return later to spawn again.

THE FRESHWATER EEL. Another somewhat similar life-story is that of the common eel. The eels of European ponds and rivers pass out to sea when mature. They travel at night and, pressing ever forward, may even wriggle for long distances over damp grass (cp. p. 313). Once in the sea, they swim for hundreds of miles until, arrived in the deep waters of the west Atlantic, they spawn and die. The eggs hatch, the young *fry* come to the surface, and soon the delicate larvae begin their long journey back to the European rivers from whence the parent eels came.

About eighteen months elapse before, as *elvers*, tiny creatures about 2½ inches long, they reach those rivers, many of them having travelled over 3,000 miles from the place of their birth.

BIRD MIGRATION is a big subject which we can only touch on here. Some birds do not migrate, but spend their whole life round about their birthplace, e.g. house-sparrows, rooks, and robins; others move short distances, like the gulls who come inland as winter approaches; many move a much greater distance; until finally we come to birds who fly more than half across the globe, making this journey twice a year (cp. p. 384).

The first flight of the year's fledgelings is always from a colder to a warmer latitude, the migratory bird nesting at the colder (in our hemisphere northern) limit of its range. Swallows, cuckoos, nightingales, &c., who spend the summer in England, are born here, go south as winter approaches, return and breed here, and so on; duck, fieldfares, &c., on the other hand, are winter visitors; their nests are far north, often within the Arctic zone.

The routes these birds follow, the rates at which they fly, the stimuli which drive them to undertake such journeys—these and many other allied problems are being intensively studied. Perhaps the best way of realizing how great these problems are is to study some definite stories of bird migration.

SWALLOWS. Every spring, usually in April, the first swallows

appear in England. To those who know their story, the sight of these new arrivals darting here and there over house or barn is indeed a thing to stir the imagination. The birds have probably come from the eastern coast of South Africa. The process of ringing, i.e. of placing a light aluminium ring round a young bird's foot, has enabled us to trace some of them, and many birds ringed in the British Isles have been caught in Africa or on the way there.

'The astonishing thing is that they are all clustered in an area no larger than Great Britain on the eastern seaboard of the Union, i.e. looking not on the Atlantic but on the Indian Ocean.'

'There must be a definite concentration of British swallows in winter quarters at the farthest end of Africa, seven thousand miles from home as the crow is reputed to fly, and perhaps ten thousand as the swallow flies, foraging continually as he skims over fields and waters at an easy 25–30 air-miles per hour.' (*The Wreck of the Swallows*, by E. Nicholson.)

In spite of the enormous distances they travel, swallows have often been found to return to the same spot year after year.

'A swallow marked in Aberdeenshire in 1912 returned to the same farmstead the following year. A swift ringed in Ayrshire in 1914 was recaptured in the same place in 1918, having doubtless been to Africa four times in the interval.' (Thomson, *Biology of Birds*.)

Remembering all this, is it remarkable that the arrival of the first spring swallows stirs the imagination of the bird-lover? Very soon after they appear the birds are busy nest-making, their half-cup-shaped nests, built of mud and straw and lined with feathers and fine grass, being very familiar. Two or three broods are hatched, and then they are off on their long journey once more, the young birds leaving first, the older ones going some weeks later. The majority of British-born swallows seem to follow the Atlantic seaboard fairly closely, crossing the Mediterranean at the narrow Gibraltar end. Whether they double the Cape of Good Hope or fly across country to reach their winter quarters is still unknown.

THE CUCKOO. This bird, which, like the swallow, is a summer visitor, is interesting because of its nesting habits. It is a parasite (cp. p. 195), laying its eggs in other birds' nests

and leaving its young to the care of foster-parents. With considerable stealth the cuckoo introduces its egg into the nest of some other bird, such as a hedge-sparrow or meadow-pipit, either laying it in the nest or depositing it on the ground and then placing it in the nest with its beak.

When the young cuckoo is hatched it ejects its foster-brothers and -sisters; the slightest touch sends the cuckoo fledgeling into strong convulsions, and it is during this upheaval that the other nestlings are thrown out. It is a curious comment on bird mentality (cp. p. 219) that the foster-parents make no effort to rescue their own young, but go on diligently feeding the intruder, the feeding being continued for some time even after the youngster has left the nest.

Another puzzling fact in this curious life-history is that the adult (parent) cuckoos leave England many weeks before their offspring. Yet the young cuckoo, knowing no parental care or training, often brought up by birds who do not migrate, sets off after its parents when the appropriate time comes.

THE PROBLEMS OF MIGRATION. These life-stories make clear how great are the biological problems connected with migration. What is the origin of this racial habit? What drives a salmon to leave the rich feeding-grounds of the open sea and make its way up some small river? Or the eel to leave the safety of its pond for that great migration to the south Atlantic? Or the swallow to leave the rich African country for our islands with their less luxuriant insect life? Obviously it is not just the call for food. The impulse is inborn; the cuckoo, eel, and salmon migrate, although they never see their parents. They do not go as the result of any teaching. How do they know when to go or where to go? How do they find their way?

We cannot answer these questions; biology is a young subject, and all through our work we light upon these great unsolved problems.

QUESTIONS ON CHAPTER XXIX

1. What conditions are necessary for a baby to develop into a healthy adult? How do you think the conditions under which we live might be improved to that end?

2. Give a short, illustrated account of the general processes of development from the egg of a vertebrate animal.

3. Describe the changes in external features which take place during the life-history of the frog, from the earliest tadpole stage to the stage of the small frog. (J.M.B.)

4. Give a short, illustrated account of the development of the frog or butterfly, commenting on any features of special interest.

5. Give a short account of the changes that take place during metamorphosis in the butterfly and the frog, and show how these changes are associated with the changes in the method of locomotion and of obtaining food. (L.G.S.)

6. Write a short essay on animal migration and its relation to animal growth.

7. In what way and why do seasonal activities of cold-blooded and warm-blooded animals differ? Illustrate your answer by reference to examples known to you. (J.M.B.)

8. Describe three different ways in which animals prepare for winter. Do you know of any similar methods among plants? (C.L.)

9. In what way, and why, do the seasonal activities of the 'cold-blooded' and 'warm-blooded' animals differ? Illustrate your answer by reference to examples known to you. (J.M.B.)

10. Give an account, illustrated with diagrammatic sketches, of the life-history of an insect having a metamorphosis, confining your answer to external features. (C.W.B.)

11. What do you understand by metamorphosis? Illustrate your answer by reference to any type in which this phenomenon occurs. (C.W.B.)

12. Describe carefully the life-history of any *two* butterflies or moths. (C.L.)

13. What is understood by the term 'complete metamorphosis'? What advantages does the animal gain by it? Describe three distinct stages in the developmen of the frog. (Ox.L.)

14. Contrast the external characters of the frog and the insect. What is meant when it is stated that both undergo metamorphosis? (Ox.L.)

CHAPTER XXX

GROWTH, FORM, AND MECHANICAL SUPPORT

THE ANIMAL SKELETON

As living creatures develop they not only increase in size and become more complex in structure, but gradually assume a definite and characteristic form, by which they are easily recognized. Living protoplasm is semi-fluid (cp. p. 39). Now, ordinary fluids have no form; they take that of the vessel in which they are contained. How, from liquid or gelatinous protoplasm, can a rigid structure like a tree-trunk or your own body be built up? The answer is, of course, that as growth proceeds, the protoplasm produces a framework of some kind which gives it form and rigidity. This framework consists, at least in part, of lifeless matter, and we know that it often persists after the death of the organism (cp. p. 25). It is from woody stems, shells, bones, &c.—in short, the hard parts of the body—which have remained as fossils in the rocks, that we learn a great deal about plants and animals (e.g. great reptiles, prehistoric man, &c.) long since extinct, and try to reconstruct their appearance.

MECHANICAL SUPPORT IN PLANTS

TURGIDITY. The problem of support in plants is not complicated, as it is in animals, by the necessity for locomotion, and plant protoplasm encloses itself completely in a supporting and protective framework of cell-walls. Directly a new cell is cut off its wall is formed (cp. p. 44). As we have learned already (cp. p. 96), young plants owe their rigidity entirely to pressures developed in these walls. If the cells wither or water is artificially withdrawn from them (cp. exp. 25), they collapse like so many deflated footballs, and the whole plant becomes limp and flabby.

MECHANICAL TISSUE. As plants grow older and larger, the increasing weight of branches, leaves, &c., demands greater support, and definite mechanical tissue is formed. Cell-walls become thickened by the deposition on them of additional

layers of cellulose or lignin (cp. p. 92). Such cells are often long and pointed, the interlocking of these pointed ends giving great mechanical strength (cp. Fig. 22). Stems, which have to withstand the force of the wind, the weight of snow, &c.; roots, which are exposed to the pull of swaying, top-heavy stems; leaves, which must not tear in a gale and yet must be held firmly exposed to the light—all these require different arrangements of the mechanical tissue, and it is formed where it will best comply with these varying needs—near the centre in roots, nearer the periphery in stems, and so on.

MECHANICAL SUPPORT IN ANIMALS

In animals the supporting tissue must give rigidity, but at the same time there must be freedom of movement. There is a certain conflict between these two requirements, and we find many different forms of skeleton in animals, some of which we will now examine. We may divide them roughly into:

(1) those formed on the outside of the animal (*exoskeletons*),
(2) those formed internally (*endoskeletons*).

EXTERNAL SUPPORTING TISSUE. This often takes the form of a *shell* on the outside of the animal, pierced by one or more holes through which the soft parts used in locomotion, &c., can protrude. These 'shells' are of very varied form. Tiny perforated ones are made by many unicellular marine animals (Radiolaria, Foraminifera); during the life of the creature its pseudopodia were pushed out through the perforations. Chalk and limestone rocks consist almost entirely of such shells, which fell to the bottom of the water when the animal died.

Larger shells (single or univalve, and double or bivalve) can be studied in the phylum Mollusca (snails, whelks, mussels, oysters, &c.). From these the living animal protrudes a muscular 'foot' for locomotion. Such shells, which continue to grow after they are formed, give support and protection, but they are heavy to drag about and restrict movement. Molluscs as a group are sedentary animals, escaping their enemies, not by flight, but by retreating within the shell. These shells often somewhat resemble the surroundings in which the creature lives; for example, many snails living

on chalk downs have whitish ones. (Protective coloration (cp. p. 410).)

Another form of exoskeleton is the type so familiar in a crab

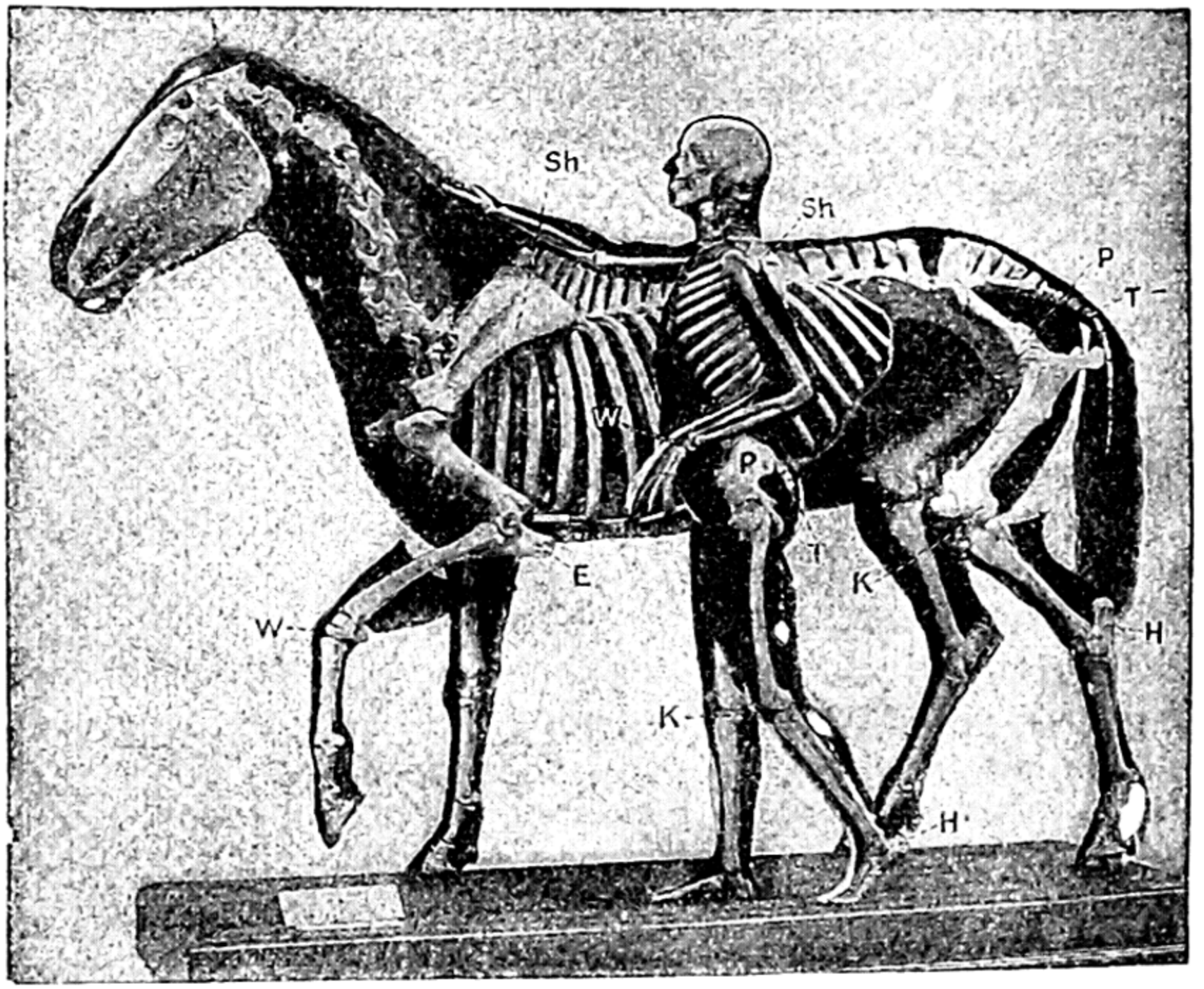


FIG. 127. Skeletons of man and horse with outline of the bodies to show the correspondence of general plan. E, elbow; H, heel; K, knee; P, pelvis; Sh, shoulder-blade; T, tail-vertebrae; W, wrist. (Brit. Mus.—Nat. Hist.)

or lobster (cp. p. 284), where it resembles a medieval coat of mail. All Arthropoda (crabs, lobsters, &c., insects, spiders) have supporting tissue on the outside of the body; it consists of a cuticle formed by the epidermal cells (cp. p. 393). In the crabs, &c. (Crustacea), it is harder than in the other subdivisions of the group, owing to its becoming impregnated with salts of lime (cp. exp. 104).

Such a skeleton has many joints, and muscles which pass across these joints are attached to it *internally* (cp. Fig. 58). It is by their contraction that the joints are moved. The

arthropods, in contrast to the molluscs, are an active clan; this form of skeleton, with its attached muscles, makes such activity possible. These creatures all have numerous legs, some of which they use for locomotion. Four pairs of walking legs are characteristic of spiders, three pairs of insects (cp. Fig. 86); many Crustacea also use four of their many pairs for this purpose.

This arthropod skeleton has one grave disadvantage. It is a dead product which, when once formed and hardened, cannot stretch; hence it hinders growth. This difficulty is partly overcome, as we have learned (cp. p. 393), by the phenomenon of *ecdysis*. When the skeleton gets too tight for the body within, it ruptures and is shed. The animal is left temporarily unprotected, but free to expand. Then the new shell hardens and there can be no further increase in size (though new cells may continue to be formed) until the next moult. Many examples of this method of growth are given on p. 393. Ecdysis continues all through life in some arthropods, e.g. in the crayfish, but is always far more frequent in early life, when growth is rapid. The adult crayfish only casts its 'crust' once a year.

Ecdysis ceases in insects when the winged animal is formed. It does not occur in the mature insect.

Exercises

Examine pictures or prepared microscope slides of Foraminifera and Radiolaria.

Collect and examine the shells of any molluscs, e.g. snails, which occur near your home or school. Observe the living animal, and discover what you can about its way of life. It is interesting to collect a large number of *one* kind of shell, and to observe the amount of individual variation.

Examine the external structure of a crayfish, a crab, and of a beetle —or other insect. Notice particularly the exoskeleton, examine the joints, and ask yourself how much movement they allow.

THE VERTEBRATE ENDOSKELETON

In the animals we have just examined the supporting tissue was exclusively or largely external. In vertebrates it is essentially internal, although, in scales, nails, hoofs, horns, &c., we

have in this group, too, a skin skeleton. There is a great similarity between the skeletons of all vertebrates; indeed, the name of the group is derived from their characteristic backbone of separate vertebrae.

We may conveniently distinguish between:

(*a*) The *axial* skeleton, which supports the head and trunk.

(*b*) The *appendicular* skeleton, which supports the limbs or fins.

The *axial skeleton* consists of:

(1) The *skull* and the bony supports of eyes, ears, nose, and jaws, these latter constituting the bones of the face.

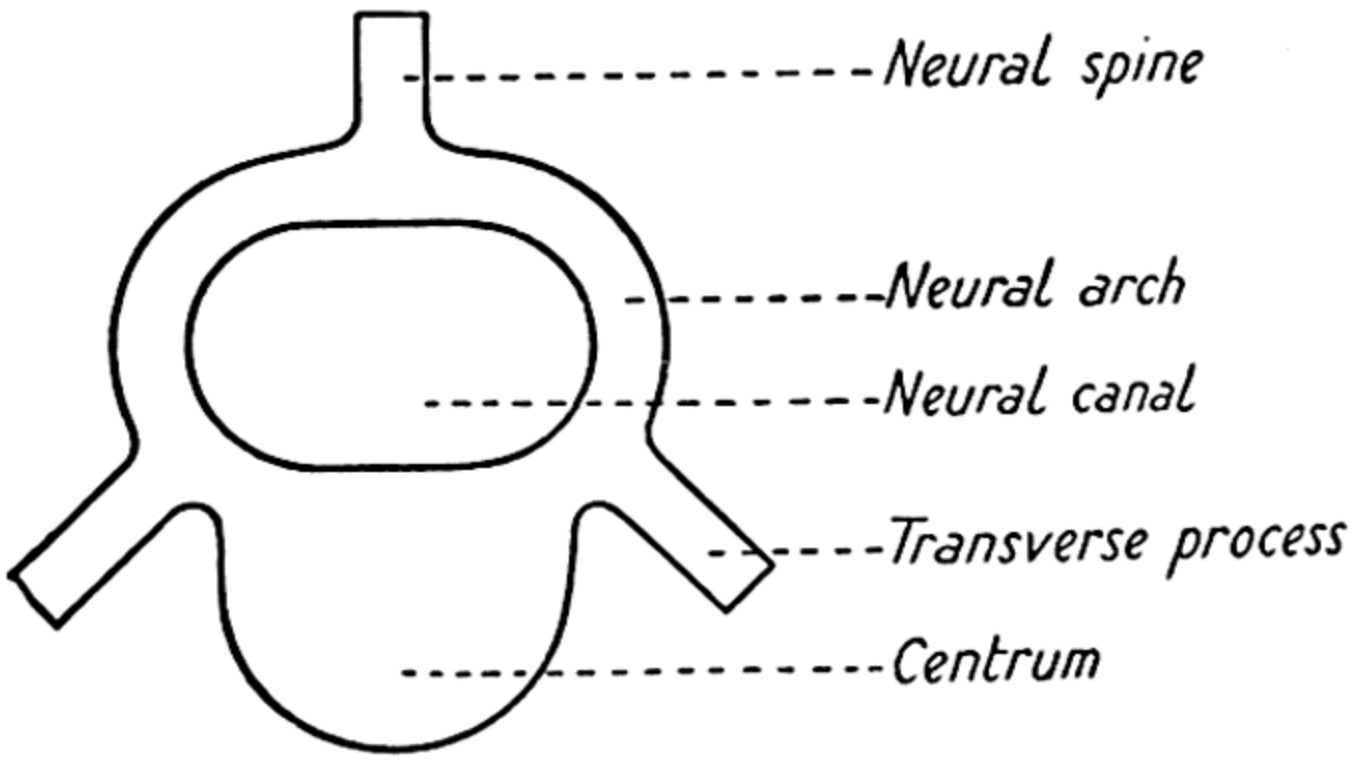


FIG. 128

(2) The *vertebral column*, which exhibits metameric segmentation, being made up of separate vertebrae all similar in structure, to some of which ribs are attached.

The structure of a typical vertebra is shown in Fig. 128.

The *appendicular skeleton* consists of two *limb-girdles* supporting two pairs of *pentadactyl limbs*, or, in fishes, two pairs of fins. (There is skeletal tissue, too, in the median fins (cp. p. 288).) In all land vertebrates (amphibia, reptiles, birds, and mammals) the skeleton of limbs and limb-girdles can be referred to one generalized plan. The girdle consists of two half-hoops of bone, each hoop consisting of three bones arranged as in Fig. 129. The limb articulates where the three bones meet. The names applied to these

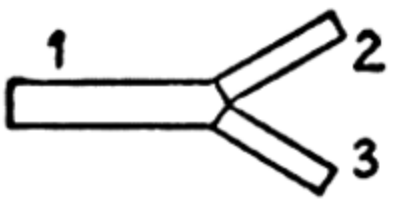


FIG. 129

bones in pectoral and pelvic girdles respectively are shown below (Fig. 130), while Fig. 131 illustrates the general plan of the limb of land vertebrates. Such limbs are called *pentadactyl.*

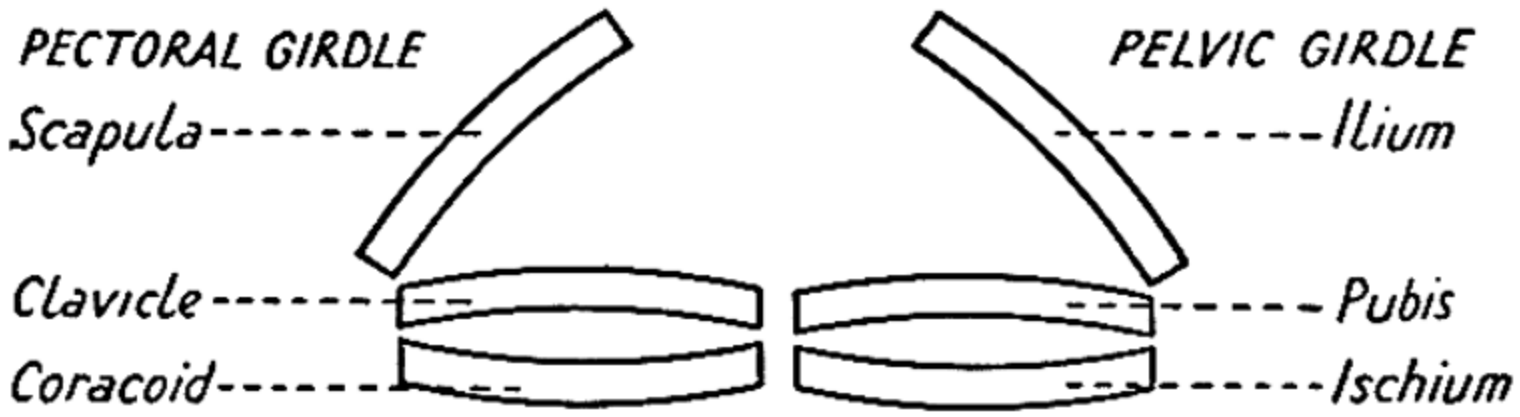


FIG. 130

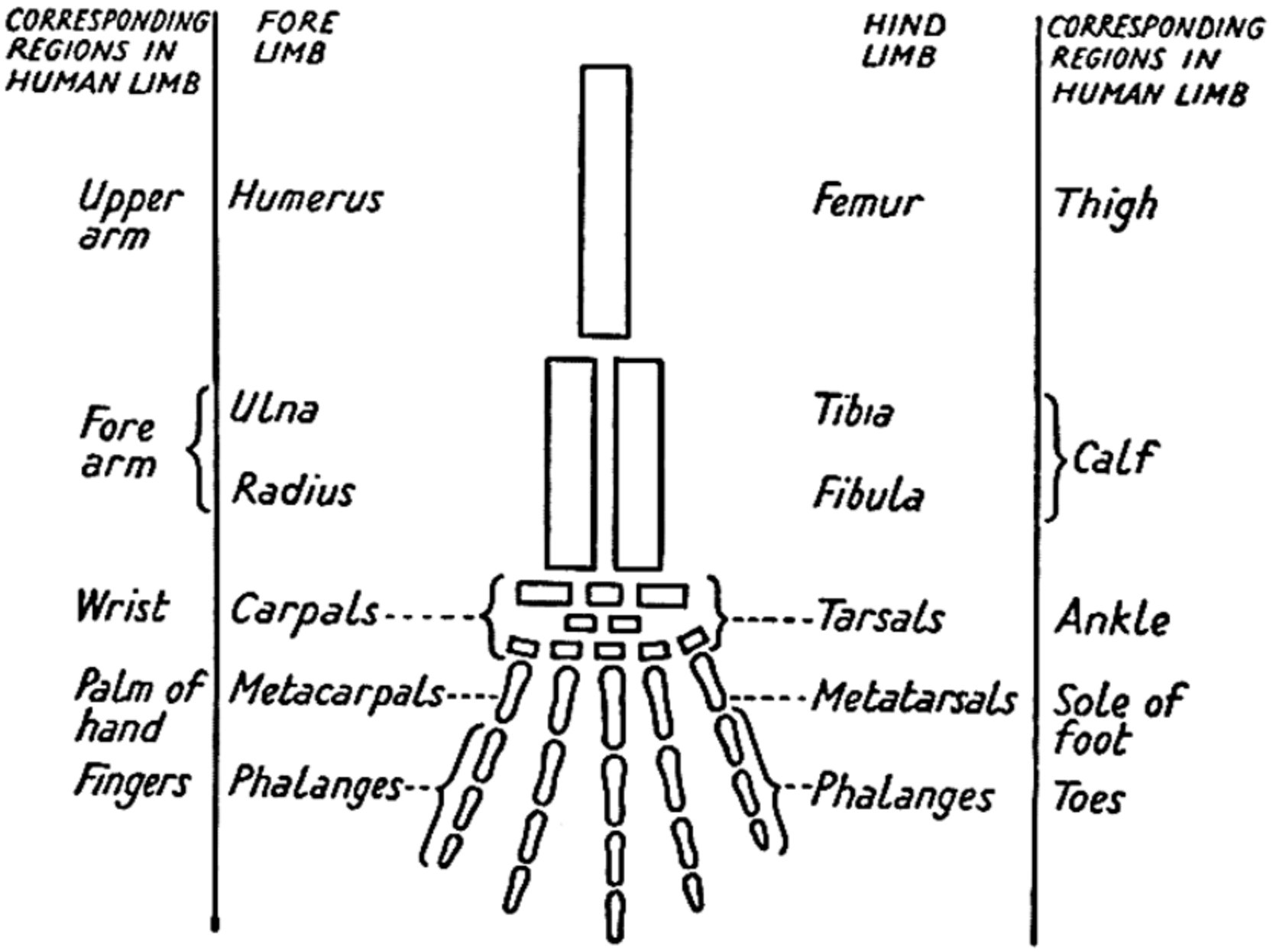


FIG. 131

'Nowhere, perhaps, in the animal kingdom does one meet such a host of variations of one fundamental ground-plan as in the limb-skeleton of the higher vertebrates' (Dakin). Let us now examine in more detail the skeletons of some characteristic members of this phylum.

Exercise. Examine and sketch (*a*) mounted skeletons, (*b*) separate bones, of certain vertebrate animals, e.g. of a fish, frog, bird, and mammal. If possible examine one of a human being. You will probably find it possible to obtain the skeleton, or parts of the same, of a fish, a domestic fowl, and a rabbit, at home. Collect the bones of these creatures when they have been used for food, well boil them, and pick off the remaining flesh.

Experiment 104. Take two rabbit bones (the femur is very suitable) and weigh each separately. Place one in dilute hydrochloric, and leave for a week or two, changing the acid once or twice. Then dry the bone and weigh it again. It has lost some 67 per cent. of its weight and is now quite soft and flexible.

Break up the second bone and heat it strongly in a crucible. It becomes black, later it turns white, and finally all that is left is a crumbling, brittle mass. Weigh this; it represents 33 per cent. of the original weight of the bone, and contains all the mineral salts. (These will dissolve in hydrochloric acid. Try this.) The gelatinous framework left when these salts were dissolved out from the first bone represented the organic substratum of the bone.

THE FROG SKELETON. The *skull* consists of the bony brain-case (cranium), of nasal, ear, and eye capsules, and of the bones of the upper and lower jaw, the former being firmly attached to the cranium.

The *vertebral column* consists of nine vertebrae, all very similar in form, and of an unsegmented bony rod, the urostyle. All these vertebrae, except the first, bear transverse processes, at the ends of which are small knobs of cartilage, representing the frog's very undeveloped ribs. The transverse processes of the ninth vertebra are large and directed backwards; they serve for the attachment of the pelvic girdle. The centrum of a typical vertebra (2–7) is concave in front, convex behind, the protuberance of the first fitting into the concavity of the next in the series. Eight and nine are biconvex; one is modificd anteriorly to bear the skull.

THE APPENDICULAR SKELETON. In the *pectoral girdle* of the frog we recognize scapula, clavicle, and coracoid. The two ventral ends of this girdle are united by the sternum or breast-bone.

The *fore-limb* is short and weak, and of little use in locomotion. There are four in-turned toes. The skeleton of this limb conforms to the plan outlined on p. 405 in Fig. 131. The chief points of divergence are:

(*a*) The ulna and radius are fused.

(*b*) There are only six carpals.

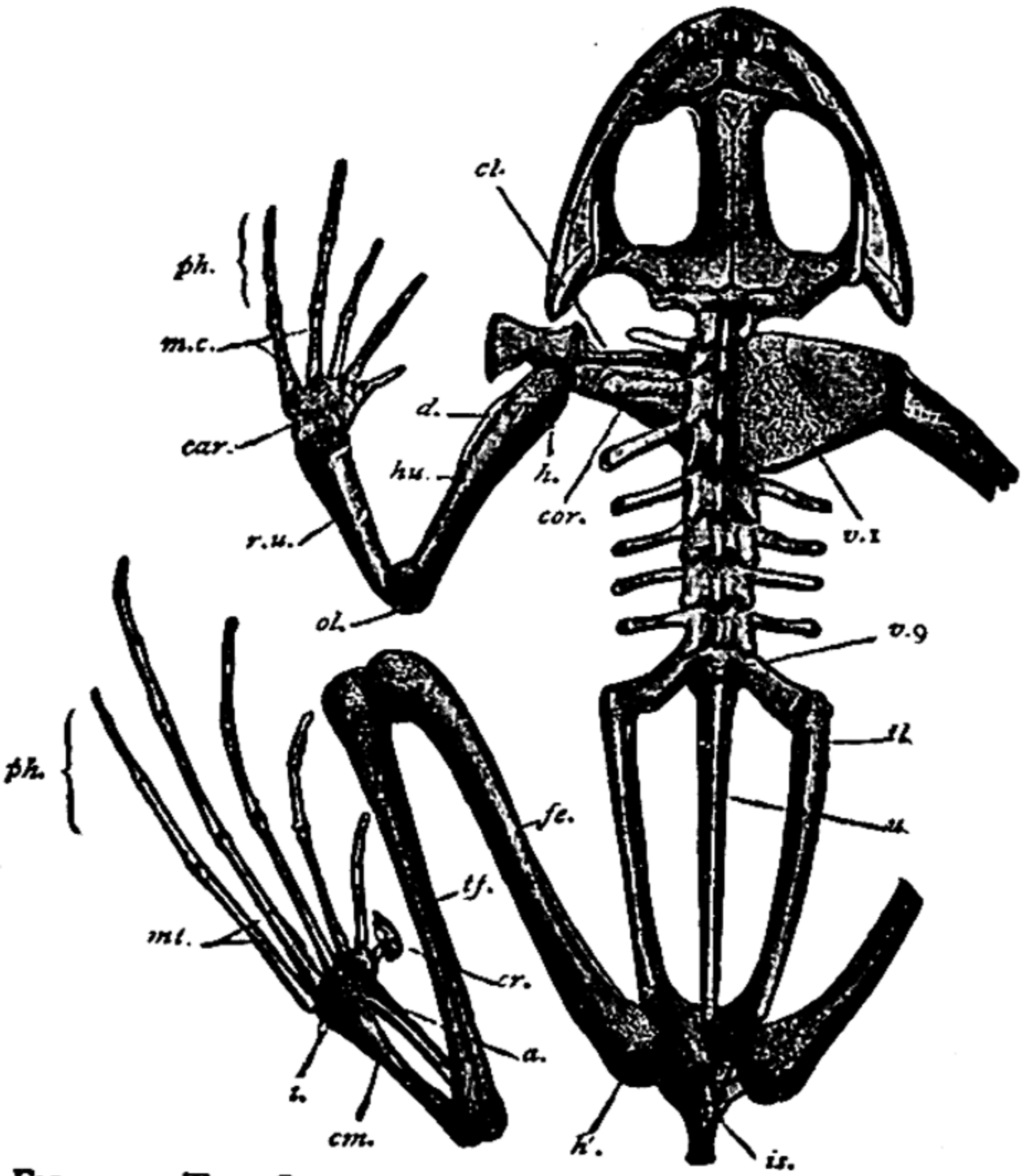


FIG. 132. THE SKELETON OF A FROG, SEEN FROM ABOVE. *a.*, astragalus; *car.*, carpal or wrist bones; *cl.*, clavicle; *cm.*, calcaneum; *cor.*, coracoid; *fe.*, femur; *h.*, *h.'*, heads of humerus and femur; *hu.*, humerus; *il.*, ilium; *is.*, ischium; *m.c.*, metacarpals; *mt.*, metatarsals; *ol.*, olecranon process; *ph.*, phalanges; *r.u.*, radioulna; *t.*, distal tarsals; *tf.*, tibiofibula; *u.*, urostyle; *v.*1, first or atlas vertebra; *v.*9, ninth or sacral vertebra. The dotted regions consist of cartilage. The cartilage at the ends of the limb bones is the 'articular' cartilage which caps the enlarged ends of the bones

(*c*) There are only four complete digits, two of these with two joints only, two with three.

The *pelvic girdle* is less typical, departing rather widely from the usual plan, though the three characteristic bones are recognizable. It does not support the abdominal organs, but lies almost parallel to the backbone, its chief function being to afford attachment to the powerful leg-muscles which serve the animal for its swimming and leaping movements. The ischium and pubis are very short.

The *hind limb* of the frog is well developed and adapted for both leaping and swimming. Notice the long toes connected by a 'web' of skin.

The most obvious specialized features in the skeleton of this limb are:

(*a*) The tibia and fibula are joined.
(*b*) Two of the tarsals (there are only four) are much elongated and are joined at each end.
(*c*) There are five long, thin metatarsals.
(*d*) The numbers of phalanges in the toes, numbering these from the first to the fifth toe respectively, are 2, 2, 3, 4, 3.

THE BIRD SKELETON. A bird shows specialization of structure in all parts of its body which adapts it for flight. The skeleton, for example, although conforming to the usual vertebrate plan, exhibits many very distinctive features. Among these, if we examine the skeleton of a pigeon, we observe:

I. The bones are very light; many are hollow and contain air-spaces. The advantage of this is obvious.

II. The vertebrae of the trunk region (about twelve in the pigeon) are fused together and are also joined rigidly to the pelvic girdle, so that a very firm support is obtained for the two hind legs, on which the whole weight of the body rests.

III. The vertebrae of the neck (fourteen in the pigeon) are very freely movable. This compensates to some extent for the unusual rigidity of the backbone lower down.

IV. The sternum, to which the larger muscles that move the wings are attached, consists of a single large bone with a prominent keel (e.g. the 'breast-bone' of a fowl).

V. The pectoral girdle is well developed, the usual three bones being present. (The 'wish-bone' of a fowl represents its clavicles.)

VI. The skeleton of the hind limb is of the usual pentadactyl type, but there are never more than four digits in any bird.

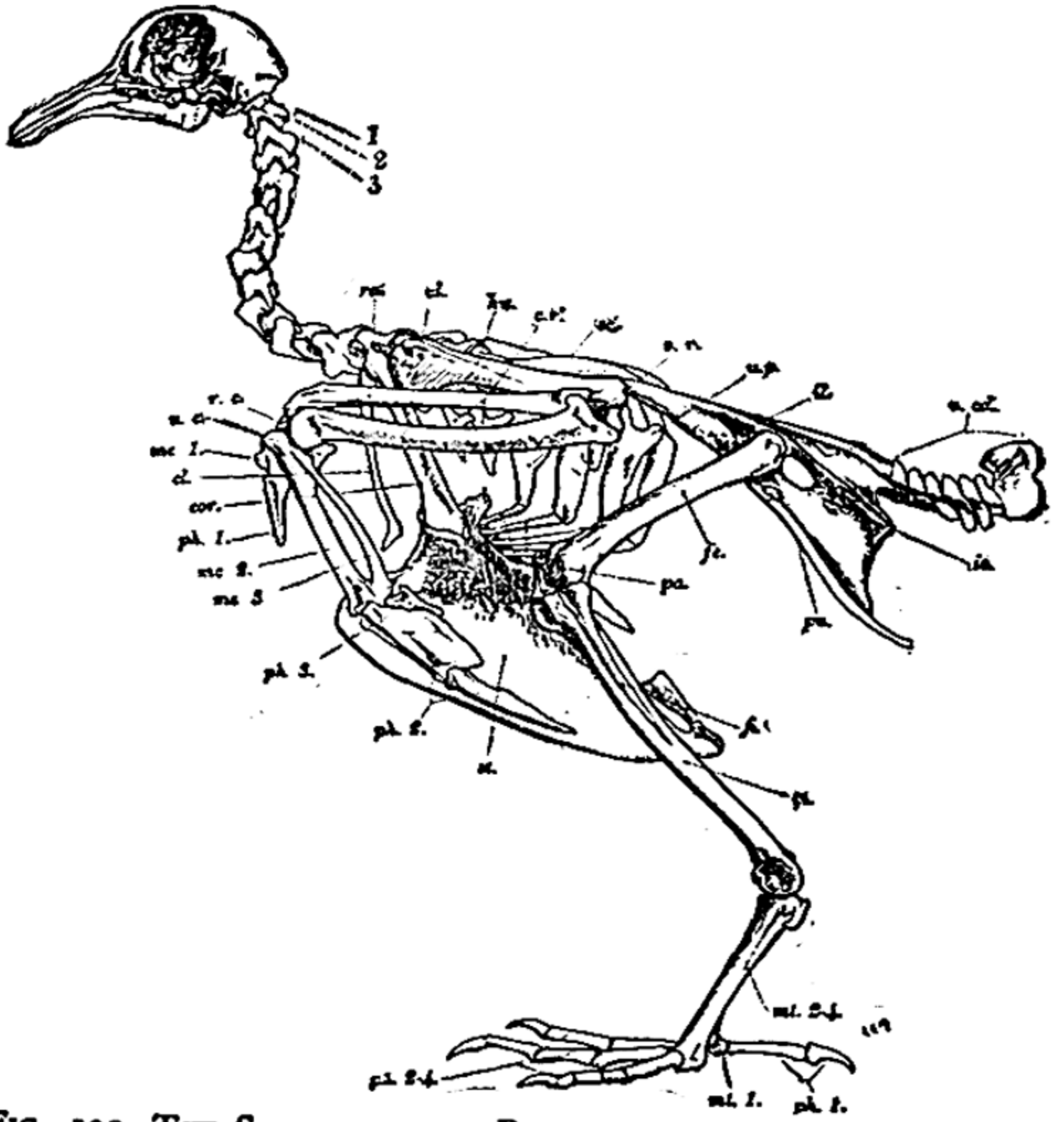


FIG. 133. THE SKELETON OF A PIGEON, SEEN FROM THE LEFT SIDE. *c.r.'*, cervical ribs; *cl.*, clavicle; *cor.*, coracoid; *fe.*, femur; *fi.*, fibula; *hu.*, humerus; *il.*, ilium; *is.*, ischium; *mc.* 1–3, metacarpals; *mt.* 1–4, metatarsals; *pa.*, patella; *ph.* 1–4, phalanges; *pu.*, pubis; *r.c.*, radial carpal; *ra.*, radius; *sc.*, scapula; *st.*, sternum; *ti.*, tibia; *u.c.*, ulnar carpal; *ul.*, ulna; *v.cd.*, caudal vertebrae; *v.r.*, vertebral rib; 1–3, first three cervical vertebrae

VII. The fore limb is much modified. Humerus, ulna, and radius are easily recognized, but the bones of 'wrist' and 'hand' are not so clear. There are only three fingers, and a greatly reduced number of carpals, metacarpals, and phalanges. The whole structure forms a framework for the attachment of the large wing feathers. These feathers are stiff, and so do not require to be stretched between two supports, as is, for example, the bat's wing.

VIII. The terminal vertebrae are fused to form a 'plough-share'.

THE BIRD, ITS EXTERNAL APPEARANCE AND ITS FEATHERS. Birds have such a characteristic appearance that any member of the group is easily recognized. The mere fact that feathers are found on them is enough. These feathers serve to keep the body warm, no matter how fast, how far, or how high the bird may fly. They give it smoothness of outline. They are coloured, helping the bird, in some cases, to escape detection (protective coloration), in others to attract its mate (e.g. the peacock). Finally, feathers are used in flight. 'What made the bird's flight possible was the growth of feathers' (J. A. Thomson). *Feathers*, which are epidermal structures, are of three main types:

(*a*) the large quill-feathers, found on the outer edges of the wings and tail;

(*b*) the contour feathers which cover the body;

(*c*) the delicate feathers (filoplumes) found among the contour feathers; these are removed from a plucked fowl by singeing.

Some birds have delicate plumules or true down feathers beneath the quill-feathers; these are not found in the pigeon.

All these feathers overlap, and can be moved by muscles attached to their lower ends. They are moulted once (or sometimes twice) a year.

Exercise. Examine one of the large quill-feathers of a pigeon. It consists of quill and vane. The quill is continued down the vane as the rachis. The vane consists of parallel rows of barbs, linked to one another by barbules, which may be held together by interlocking hooks.

A feather, with its barbs united, forms a stiff but elastic vane which does not allow air to pass through it.

EXTERNAL APPEARANCE OF A TYPICAL BIRD.

Exercise. Examine a pigeon or other typical bird, observing both the living animal and stuffed specimens. Confirm the following facts:

(*a*) *The head.* There are paired eyes, protected by an upper and lower eyelid, and by a third one, the 'nictitating membrane', in the corner of the orbit; external ears without pinnae; paired nostrils; jaws ensheathed in horn, which takes the place of teeth.

(*b*) *The trunk.* The whole body is graceful in form (until stripped of its feathers) and well adapted to rapid flight. The wings (fore limbs) bear many large quill-feathers (remiges). There are twenty-three of these in the pigeon, borne by ulna, carpals, and metacarpals. The hind limbs are covered with scales, resembling those of reptiles, and they can be pressed against the under surface of the body during flight. In the pigeon and many other birds the first of the four toes is directed backwards.

(*c*) *The tail.* This bears stiff, highly specialized quill-feathers (twelve in the pigeon); it is used for steering and to check the motion of the bird as it alights.

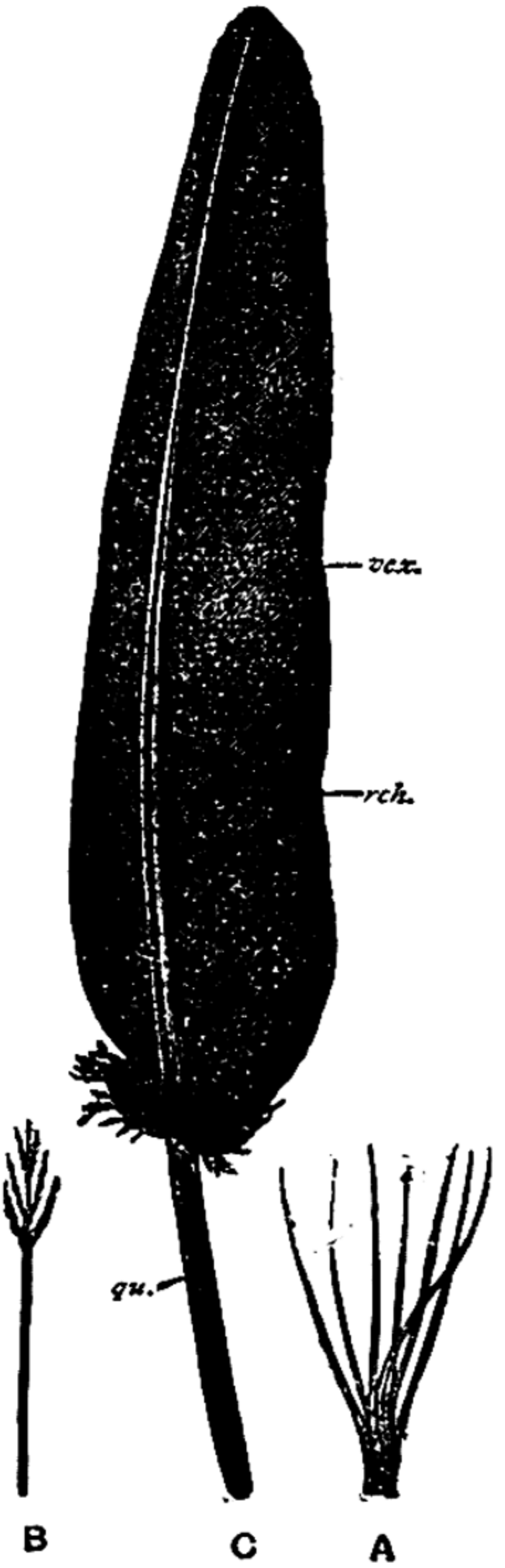


FIG. 134. FEATHERS OF A PIGEON. A. Down feather. B. Filoplume. C. Quill-feather. *qu.*, quill or calamus; *rch.*, rachis or shaft; *vex.*, vexillum or vane

THE RABBIT SKELETON.

The axial skeleton. The skull, with its cranium, its nasal, eye, and ear capsules, and the jaws, is examined on p. 216. We notice in particular the teeth, adapted to the rabbit's vegetable food (cp. p. 164); also the false palate, a secondary roof to the mouth which brings the internal openings of the nasal passages far back, near the glottis. The very characteristic sutures by which the skull bones are fused should be observed.

The vertebral column consists of vertebrae formed on the plan shown in Fig. 128. On these vertebrae we observe articular facets on the anterior and posterior articular processes; they mark the places where these bones are jointed together to form a flexible column. The vertebrae are held together by ligaments and between them are disks of cartilage known as the intervertebral disks. The vertebrae in the rabbit fall into five groups:

(1) The seven *cervical* vertebrae of the neck. The first two of these are greatly modified in connexion with the support and movement of the skull.

The first or *atlas* vertebra is ring-like; its transverse processes are very wide for the attachment of some of the muscles which support the head. The head articulates on two condyles, the joint allowing nodding movements. The neural canal of this vertebra is large and crossed by a stout ligament which holds the odontoid peg of the second or *axis* vertebra in position. This odontoid peg represents the centrum of the first vertebra, which becomes fused with the second in the course of development. It projects forward from the centrum of the axis into the cavity of the atlas and acts as a pivot. When the head is turned, the head and atlas vertebra move together, turning about this peg as a pivot.

The remaining cervical vertebrae are chiefly distinguished by the presence on each side of the centrum of a vertebrarterial canal. This canal is formed by the fusion of the rudiment of a cervical rib with the transverse process and centrum of the corresponding vertebra.

(2) The *thoracic vertebrae* (twelve or thirteen) have long thin neural spines, and bear the ribs. A rib is a double-headed structure usually articulating in two places; the *capitulum*, or ventral head of the rib, is joined to the backbone between two adjacent vertebrae, while the *tuberculum* or dorsal head articulates with the transverse process of the more anterior of these two vertebrae (cp. Fig. 136). All these facts can of course only be understood with the bones before you.

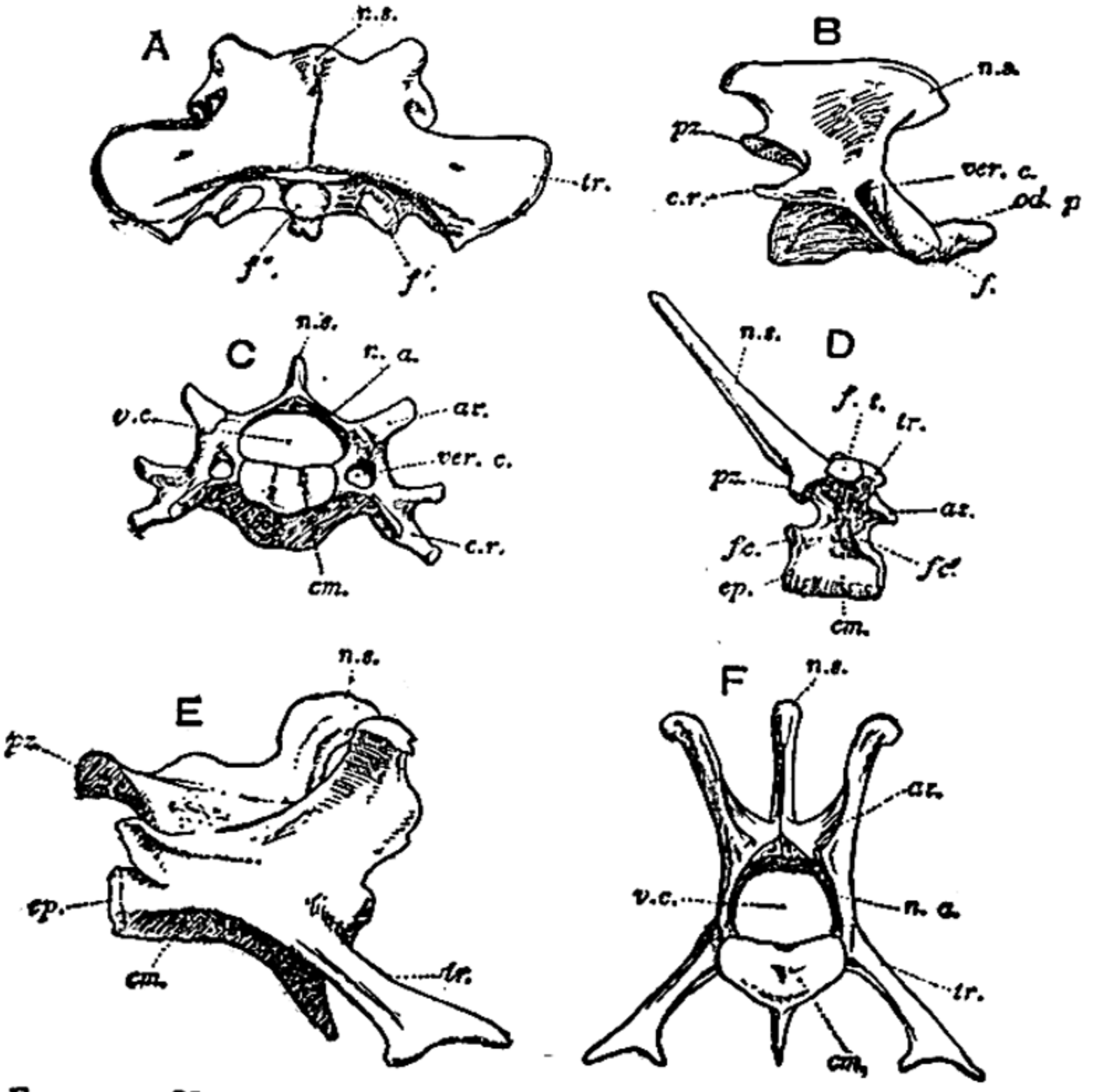


FIG. 135. VERTEBRAE OF A RABBIT. **A.** Atlas, from above. **B.** Axis, from the right. **C.** One of the middle cervical vertebrae, from in front. **D.** Fourth thoracic vertebra, from the right. **E.** Second lumbar vertebra, from the right. **F.** The same from in front.

az., anterior articular facet; *cm.*, centrum; *c.r.*, cervical rib; *ep.*, epiphysis; *f.*, facet on axis for articulation with atlas: *f.'*, corresponding facet on atlas; *f.''*, facet on atlas for odontoid process; *f.c.*, *f.c.'*, demi-facets for heads of ribs; *f.t.*, facets for tuberculum; *n.a.*, neural arch; *n.s.*, neural spine; *od.p.*, odontoid process; *pz.*, posterior articular facet; *tr.*, transverse process; *v.c.*, neural canal; *ver.c.*, vertebrarterial canal

(3) The *lumbar* vertebrae (seven or six) are large and strong (cp. Fig. 135 E), with large transverse processes.

(4) The *sacrum* consists in the adult of four fused vertebrae; these form a wedge-shaped mass of bone, and the pelvic or hip girdle articulates with the transverse processes of the first of these vertebrae.

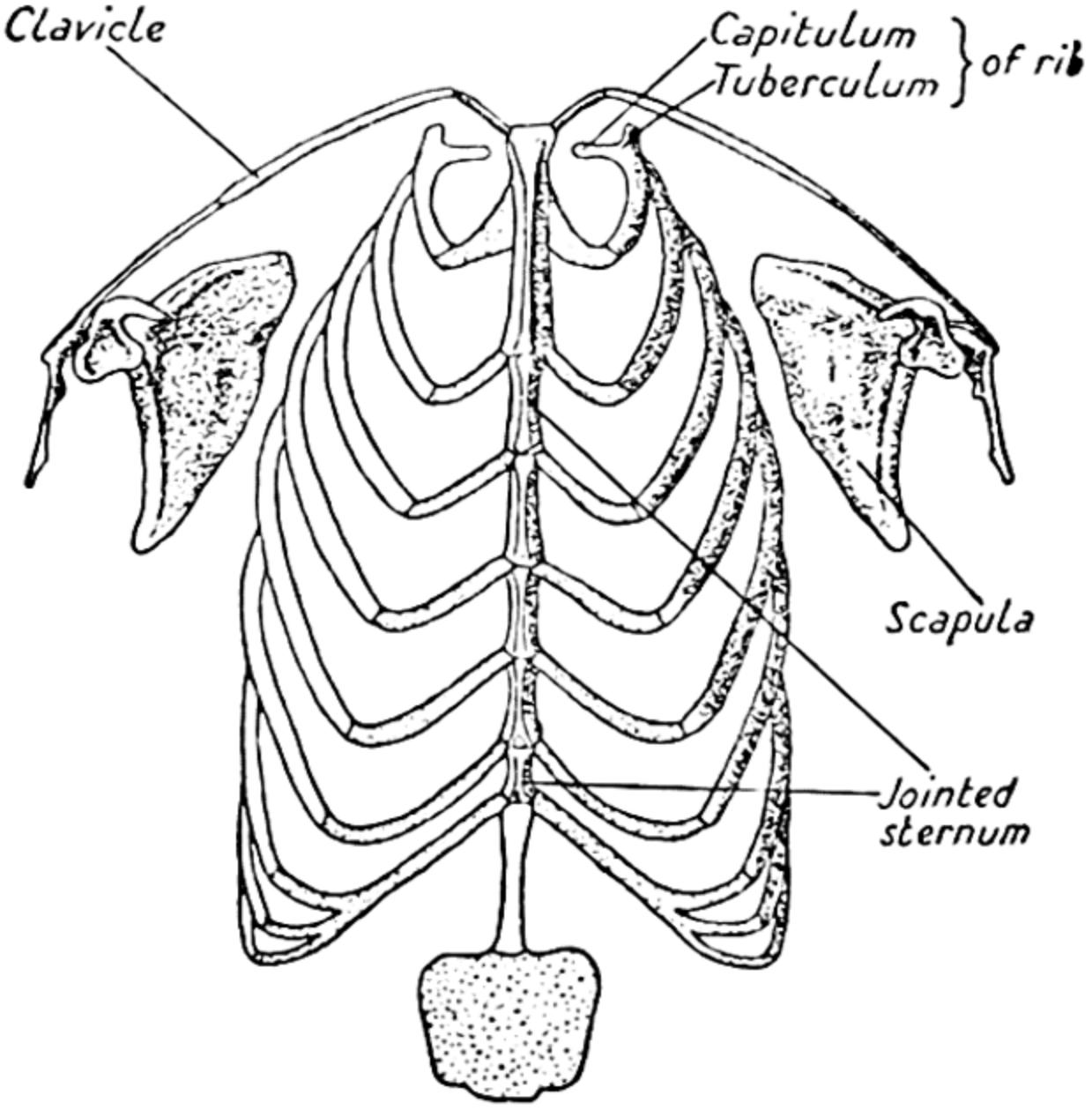


FIG. 136. The breast-bone, shoulder blade, and first nine pairs of ribs of rabbit (somewhat diagrammatic)

(5) The *caudal* vertebrae (sixteen or more) gradually lose the characteristics of vertebrae as we approach the tip of the tail. The terminal ones even lose their neural canals and become reduced to small bony centra (cp. Fig. 137 A).

The ribs. There are twelve (sometimes thirteen) pairs of ribs, composed of cartilage and bone, which enclose and protect the thoracic cavity. Dorsally they are attached to the backbone, the first nine having a double attachment as already described. The last three pairs have no tuberculum and hence articulate in one place only, with the centrum of the vertebra. Ventrally there is a sternum (or breast-bone) made up of seven segments (cp. Fig. 136). The first seven thoracic ribs articulate directly with this sternum; the next two are not directly connected with it, but are united by their cartilages to

the cartilages of the seventh pair of ribs; the last three pairs end freely among the muscles; these are called the floating ribs (cp. Fig. 93).

The *appendicular skeleton* consists of two limb girdles and two pairs of pentadactyl limbs, all conforming to the usual vertebrate plan.

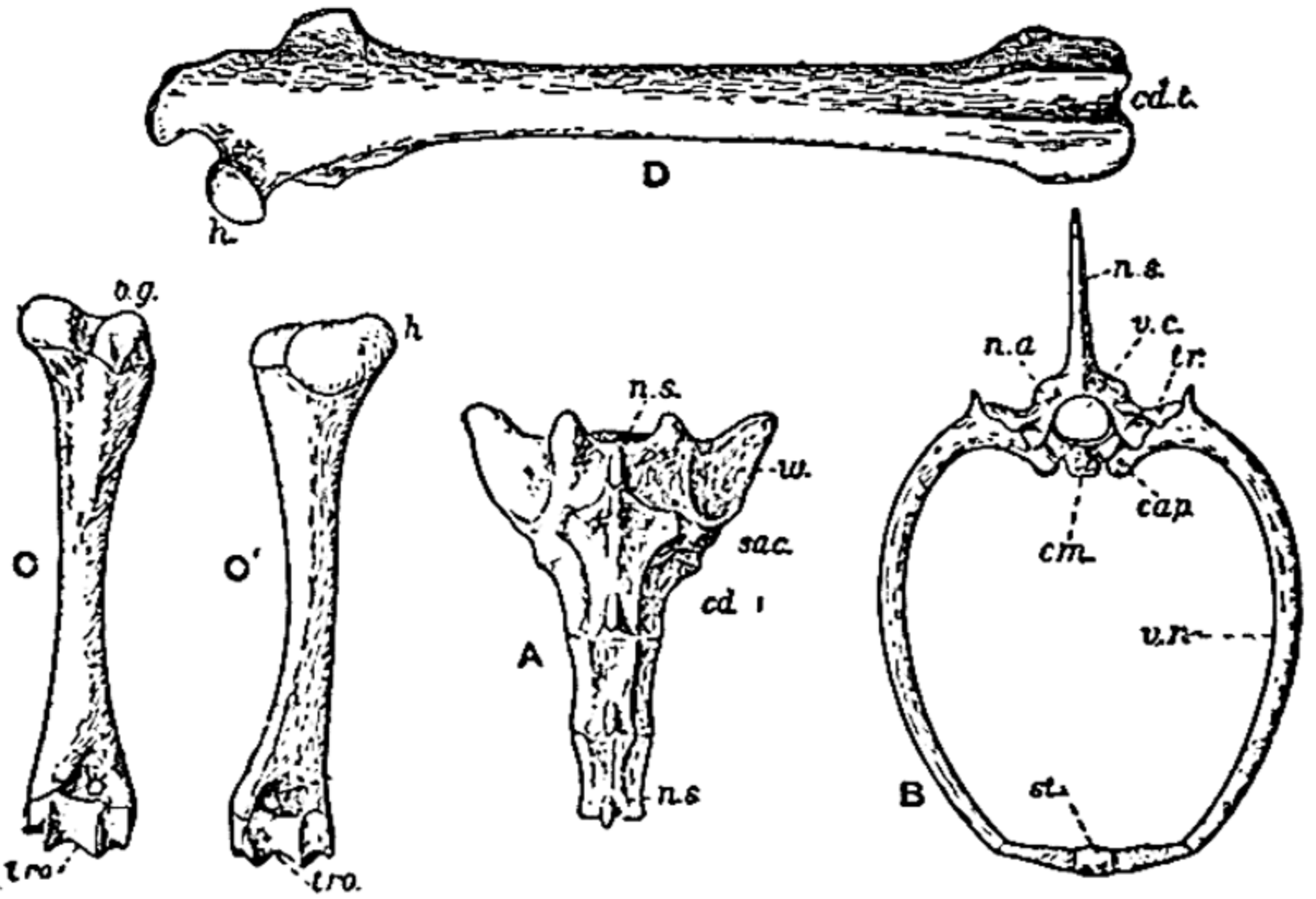


FIG. 137. **A.** Sacrum, from above. **B.** Thoracic vertebra, two ribs, and part of sternum. **C.** Left humerus from in front. **C'.** The same from behind. **D.** Left femur from in front. *n.s.*, neural spine; *v.c.*, vertebral canal; *tr.*, tuberculum of rib; *cap.*, capitulum of rib; *cm.*, centrum; *n.a.*, neural arch; *r.*, rib; *st.*, sternum; *n.s.*, neural spine; *w.*, process for ilium; *cd.* 1, first caudal vertebra; *sac.*, sacral vertebra; *h.*, head; *tro.*, articular surface for ulna; *b.g.*, articular surface for scapula; *cd.t.*, condyles for tibia

The *pectoral girdle* is reduced, but we may distinguish the large triangular scapula with a very characteristic ridge (the spine) for the attachment of muscles, and the small collar-bone or clavicle. The coracoid is only represented by a small process (cp. Fig. 136).

The *fore limb* is of the usual type; we notice the humerus, ulna, and radius, and the curved, backwardly directed projection of the ulna, the olecranon process, to which is attached the muscles which extend the 'elbow' joint. There are eight carpals, five metacarpals, and the numbers of phalanges in the digits are 2, 3, 3, 3, 3 (cp. Fig. 139).

The *pelvic girdle* shows the typical three bones, ilium, ischium, and

pubis; these are fused together and the whole girdle is rotated backwards. The deep cavity in the girdle (the acetabulum), into which the head of the femur fits, should be noted.

The hind limb. We notice the femur with its prominent head which fits into the acetabulum, the tibia, and the small fragile fibula,

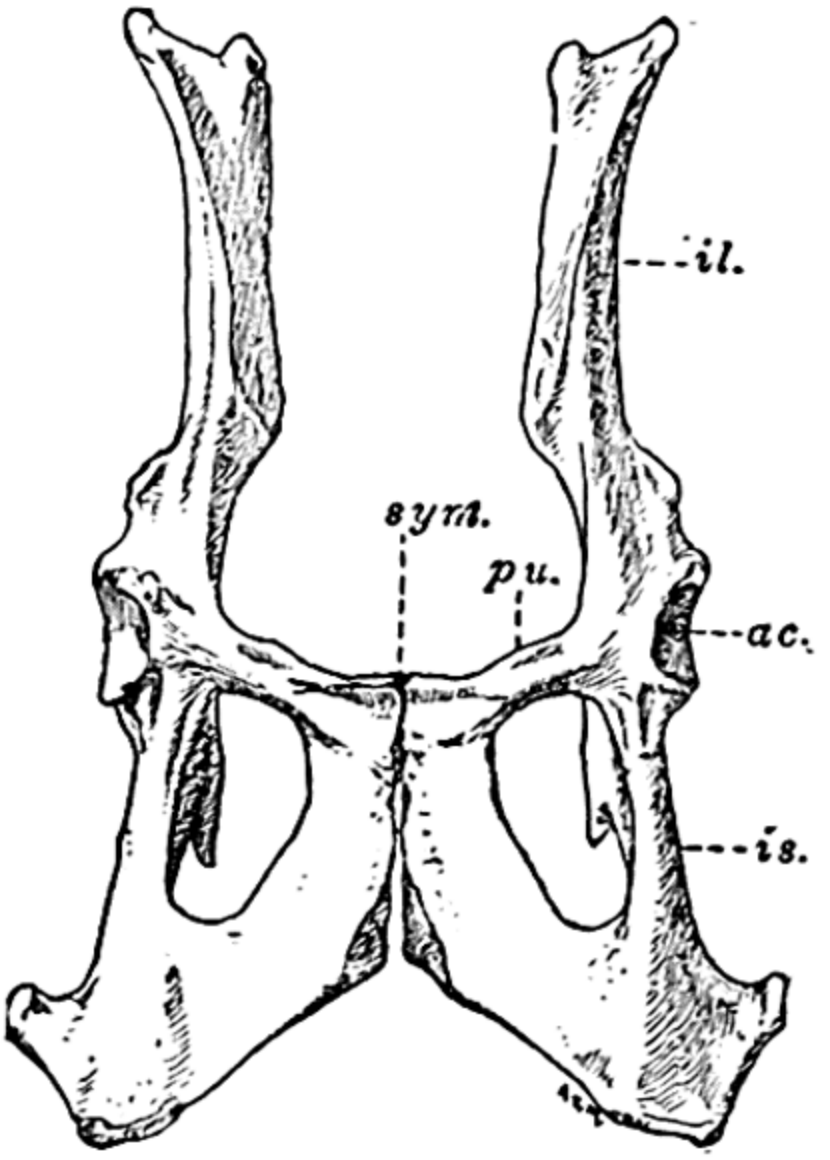


FIG. 138. The pelvic girdle of a rabbit from underneath. *ac.*, acetabulum; *il.*, ilium; *is.*, ischium; *pu.*, pubis; *sym.*, pubic symphysis

which merges into the tibia about half-way along its length. There is a small patella (or knee-cap) at the knee joint. There are only six tarsals and four digits, the rabbit's 'big toe' being vestigial. The numbers of phalanges are therefore 0, 3, 3, 3, 3.

Exercise. Having made yourself familiar with the skeleton of the rabbit, carefully compare it with the human skeleton and with those of any other mammals (cp. Fig. 127).

JOINTS AND THEIR MOVEMENT. The framework of rigid bone which builds up the vertebrate endoskeleton is jointed to admit of easy movement. Movements are caused by muscular contraction, every muscle passing over a joint and being attached to at least two bones. One set of muscles brings

the bones nearer; they return to their original position by the contraction of an opposing set of muscles (cp. Fig. 58). The action is that of the lever, the joint forming the *fulcrum*, a bone

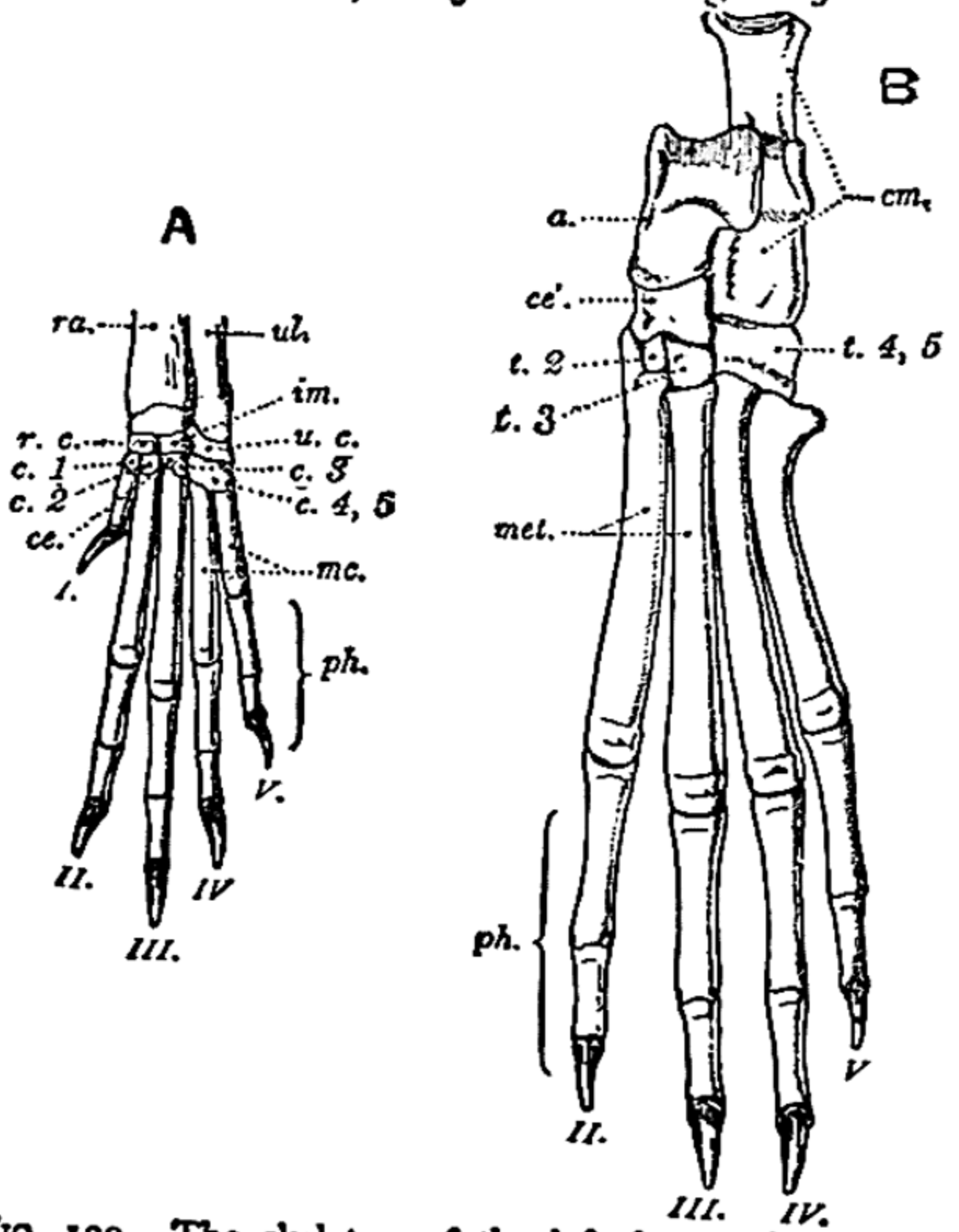


FIG. 139. The skeleton of the left fore and hind feet of a rabbit. **A.** Fore foot. **B.** Hind foot. *a.*, astragalus; *c. 1–5*, carpals; *ce.*, centrale; *ce.'*, centrale of hind foot; *cm.*, fibulare or calcaneum; *im.*, intermedium; *mc.*, metacarpals; *met.*, metatarsals; *ph.*, phalanges; *ra.*, lower end of radius with its epiphysis; *r.c.* radiale; *t. 2–5*, tarsals; *u.c.*, ulnare; *ul.*, lower end of ulnar with its epiphysis; *I–V*, digits

the *arm* of the lever; the muscles are so attached that this arm is moved about its fulcrum.

The joints show great variation; we may notice in particular:

(1) The *ball-and-socket* type of joint; these occur, for example,

where the limbs of mammals articulate with the limb girdles, and they allow of very free movement.

(2) The *hinge* type of joint which allows movement about one axis only. We find such joints at the elbow, in most mammals, also between the phalanges, &c.

At all these joints the bones are held together by firm ligaments and the joint is bathed in a lubricating fluid, the synovial fluid, which reduces friction. You should compare them with the joints in any arthropod skeleton. In those animals the exoskeleton is perfectly continuous over the whole body; at the joints it is merely thinner and more flexible. The muscles are, of course, internal (cp. p. 402).

QUESTIONS ON CHAPTER XXX

1. By what means do (*a*) herbs, (*b*) shrubs secure the rigidity needed to keep their stems erect? Describe an experiment by which you could prove the truth of your answer in the case of a succulent herb, and compare the means found in shrubs with any structures of similar functions in animals. (L.G.S.)

2. Identify and make large clear sketches of the two bones provided. Name the most important parts and explain carefully the position they occupy in the body. (L.G.S.)

N.B. The bones provided were

(1) atlas vertebra
(2) half the pelvic girdle } of a rabbit.

3. Identify and make annotated diagrams of the bone *B*. Comment briefly on its structural features. (L.G.S.)

B was a cervical vertebra of the rabbit.

4. Describe, in a general way, the position, shape, and uses of the vertebral column of a mammal. Make a descriptive diagram of a single vertebra. (C.L.)

5. What do you understand by the expression 'vertebral column'? What are its functions? Describe in general terms the vertebral column of a rabbit and (with the aid of diagrams) the detailed structure of any one vertebra you may select. (L.G.S.)

6. Show how the skeletons of (*a*) a frog, and (*b*) an insect, are adapted to suit their mode of life. (Ox.L.)

7. Compare the fore and hind limbs of a typical bird with those of a typical mammal such as a rabbit. In what ways are these limbs adapted for special purposes? (L.G.S.)

8. Describe the external characters and the skeletal structures of the fore-limb of any vertebrate animal studied by you. (C.W.B.)

9. Describe the wing of a bird and explain its action as an organ of locomotion. (B.)

10. Describe in general terms the interaction of nervous, muscular, and skeletal tissue in bringing about locomotion in insect and frog respectively. (C.W.B.)

11. What part may the skeleton of an animal play in regard to locomotion? Illustrate your answer by reference to the cockroach and the frog. (B.)

12. Describe and compare the skeleton of the fore and hind limbs of a vertebrate. (Ox. & C.)

13. Describe the methods of locomotion and the external organs which are employed in accomplishing it, in *two* of the following: a caterpillar, a mosquito larva, and a house-fly imago. (Ox. & C.)

14. What are the chief features in which an invertebrate animal like the cockroach differs from a vertebrate like a frog? (C.L.)

15. What are the functions of the animal skeleton? Contrast in general terms the type of skeleton found in the insect and the frog respectively. (C.W.B.)

16. Describe the different regions of the backbone of a mammal such as the rabbit, saying in what ways the typical vertebrae from each region differ in shape. (C.L.)

17. Describe the bones of a hind limb of a rabbit or other mammal, giving a diagram. How are these limbs attached to the vertebral column? (C.L.)

18. What are the uses of a skeleton? Illustrate your answer from the rabbit or any other mammal known to you. (C.L.)

PART VIII
REPRODUCTION

'There is no wealth but life.'

CHAPTER XXXI
REPRODUCTION. INTRODUCTORY

REPRODUCTION OCCURS IN ALL LIVING ORGANISMS. Plants and animals are not immortal; life is short, even for those who live longest. Growth soon leads to maturity, maturity to old age, old age to death.

But, before death overtakes it, the organism can beget other creatures like itself. Puppies are born and grow into dogs; seeds develop into new plants; the whole living creation obeys the urge to 'increase and multiply', and the race continues, though the individuals die.

This power of reproduction is one of the most striking characters of protoplasm; it marks a great and as yet unbridged gulf between living and lifeless matter. Let us see how the protoplasm performs this important function.

REPRODUCTION BY BINARY FISSION

An amoeba reproduces quite simply by a process of fission, its whole body being divided into two similar parts. We cannot speak here of parent and offspring; the amoeba was old; it has divided into two new animals, which are both 'young', i.e. at the beginning of their individual lives (cp. Fig. 8 B).

Many simple organisms, both plant and animal, particularly the unicellular ones, reproduce in this primitive manner.

REPRODUCTION BY BUDDING

Budding is another simple method of reproduction which occurs in many plants and animals. The new organism arises as an outgrowth on the parent. In Hydra, for example, we often see a small swelling on the side of the animal (cp. Figs. 30 and 31).

This grows larger, develops a mouth and tentacles, and eventually breaks away from its parent and swims off through the water. Soon it settles down and becomes fixed to a water-weed or other suitable object. It is a new hydra, and it originated as a bud on the side of its parent.

Exercise. Examine under a lens or microscope living hydras which have been well fed with Daphnia (water-fleas). Buds are almost certain to be found on some of them, and you may even be able to watch the detachment of one of these from its parent.

A very simple form of budding occurs in yeast plants, where the unicellular parent gives rise to a small outgrowth which represents its offspring (cp. Fig. 74). This enlarges and may itself bud before it becomes detached from its parent. Eventually all such cells become separate plants.

Exercise. Remove some actively growing yeast cells from a sugar or other nutrient solution (cp. p. 262), and examine them under the microscope. Chains of two, three, or more cells are often to be seen.

VEGETATIVE REPRODUCTION IN FLOWERING PLANTS. Vegetative reproduction is found most widely in the lower and simpler plants, but many special cases occur in flowering plants (cp. Chapter XXVIII), the process being really a kind of budding. Runners and tubers (cp. pp. 368, 372) are definite organs for this purpose; a strawberry plant often surrounds itself by a whole series of independent plantlets, each formed at the end of a runner which eventually decays; similarly every potato tuber can become the starting-point of a new plant (cp. Fig. 118).

Perennials which form rhizomes, bulbs, corms, &c., sometimes reproduce in a similar manner. Rhizomes branch and, as the older parts decay, the branches become separated. On bulbs and corms (cp. Figs. 117, 119) more than one bud may develop; these are separated as the old bulb (or corm) dies, and so each parent plant produces a number of independent offspring.

ARTIFICIAL PROPAGATION BY CUTTINGS, BUDDING, AND GRAFTING. Gardeners and horticulturists propagate certain plants from *cuttings* or *slips*, short lengths of stem which are removed

from the parent plant and caused to 'strike', i.e. produce roots, by being placed in suitable soil.

Sometimes a highly cultivated and perhaps somewhat artificial plant is grown on the root of a more vigorous wild plant of the same type, e.g. a 'double' rose on a brier or a choice dessert apple on a crab. These processes are called *grafting* or *budding*. In *budding* a single bud of the desired variety of tree is placed in contact with the cambium of the plant which is to serve as the stock. The whole shoot system is formed by the growing point of this bud (cp. p. 244), all *suckers* (i.e. shoots arising from the wild stock) being carefully removed. Roses and fruit trees are often propagated in this way. *Grafting* consists in placing together the cut surfaces of two shoots from similar plants in such a way that the two cambiums unite. The rooted plant is known as the stock. The graft of the desired plant (the scion) is a twig with several buds. The two are tied firmly together until they unite.

In all these processes the wild root gives vigour to the cultivated plant, which, like so many highly bred creatures, is often less robust than the wild one; further, large plants are obtained more quickly in this way than when grown from seed or even from cuttings. More important still, the grower can be certain that the plant he sells will be 'true to type', i.e. exactly like the parent organism (cp. p. 436). In every case the new plant develops from a bit of the parent organism. These methods of the horticulturist are obviously closely comparable to the natural processes of budding which we have just described.

Exercises

Following the method described for experiment 18, grow cuttings of willow, Tradescantia, &c., in gas-jars filled with a complete culture solution (cp. p. 72). Watch carefully the development of adventitious roots, notice where they arise, and how soon the stem of the cutting begins to grow. Sketch various stages in the development of the new plant.

In a box filled with fine soil insert cuttings of pansies, geraniums, &c. Remove one or two of them at intervals of a fortnight, wash free of soil, and investigate the development of the new root-system.

REPRODUCTION BY SPECIAL ASEXUAL REPRODUCTIVE CELLS CALLED SPORES

SPORE REPRODUCTION IN MUCOR. If you examine any well-developed growth of Mucor you will probably see, on the white flocculent mass, a number of small spherical black bodies, the sporangia (cp. Fig. 52). Each sporangium (spore-case), when ripe, contains a large number of minute unicellular spores. When the sporangial wall breaks, these cells are cast adrift on the air; each spore, given suitable conditions, can give rise to a new plant. Fungi (cp. p. 201) are the most prolific organisms in the world by reason of the enormous quantity of spores they produce. Fungal spores are always present in the air of the rooms in which we live; they have even been found in the stratosphere. Jam, &c., 'going mouldy' means that air-borne spores have germinated to reproduce the fungus.

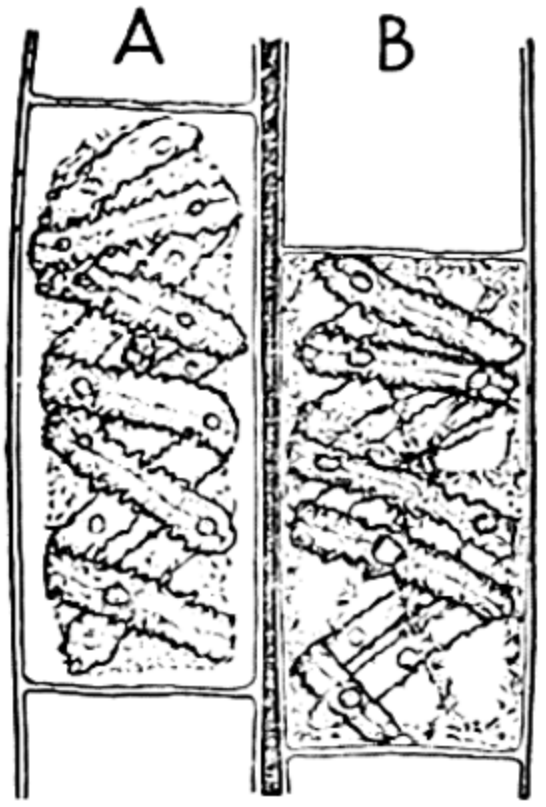
Exercise. Cut off the cap of a mushroom, place it on gummed paper slightly moistened, and cover with an inverted jam-jar. After an hour or two you will obtain a 'spore print' of this fungus.

Spore-formation is also a very common method of reproduction among green plants (e.g. mosses and ferns).

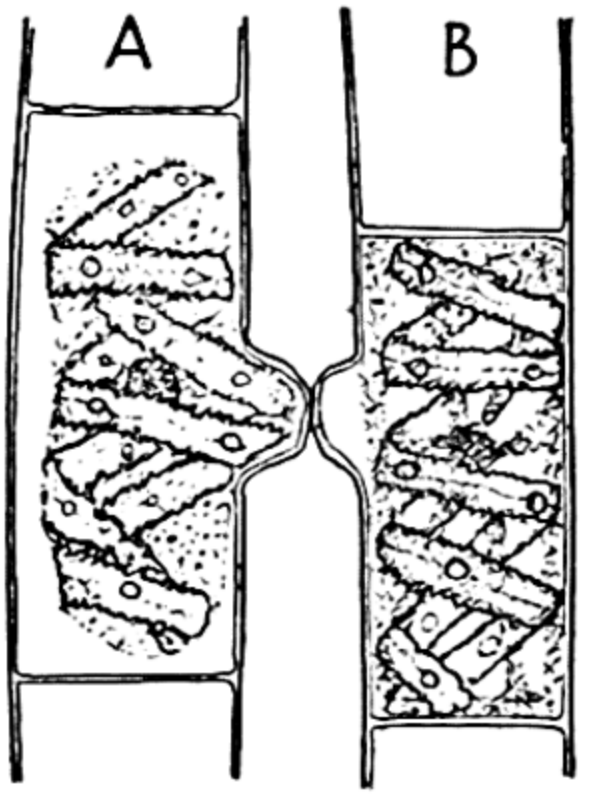
Exercises

Examine with a lens the fronds of any common fern, such as bracken or the male fern (Aspidium). On the backs of some of the fronds you will see small brown patches of sporangia; examination with the microscope reveals that each sporangium contains numerous reproductive cells, the spores. Examine any group of mosses or of those still lowlier plants, the liverworts. You will often see the spore-making capsule or 'fruit', standing up from the rest of the plant.

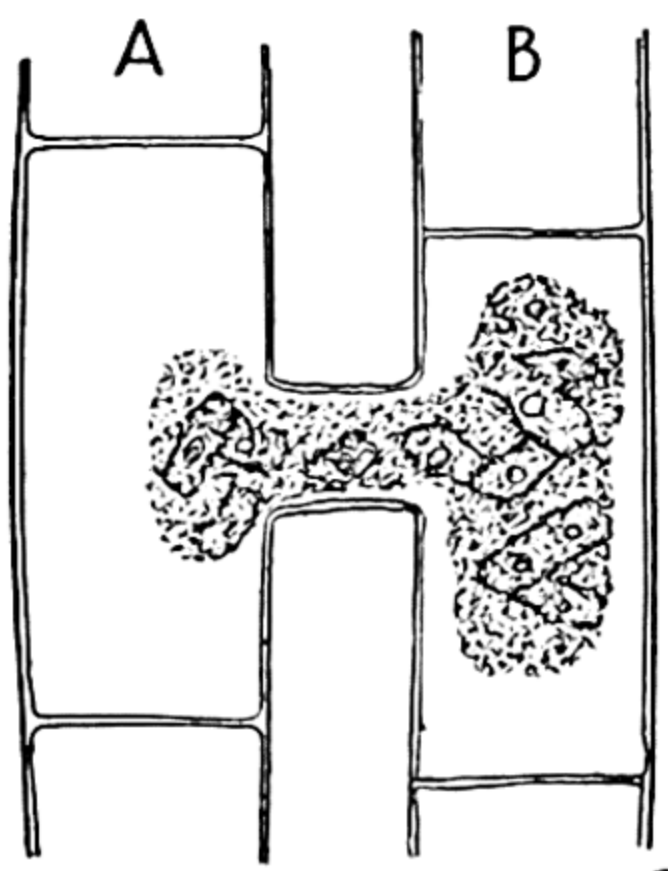
The life-history of the mosses, ferns, and their relatives is somewhat complex, involving a regular alternation of two methods of reproduction. The full story was only discovered by the scientists of the nineteenth century, and the old name Cryptogams (Gk. *kryptos* = hidden; *gamos* = marriage) was given to these plants because their method of reproduction was not clear. We know now that this reproduction by spores



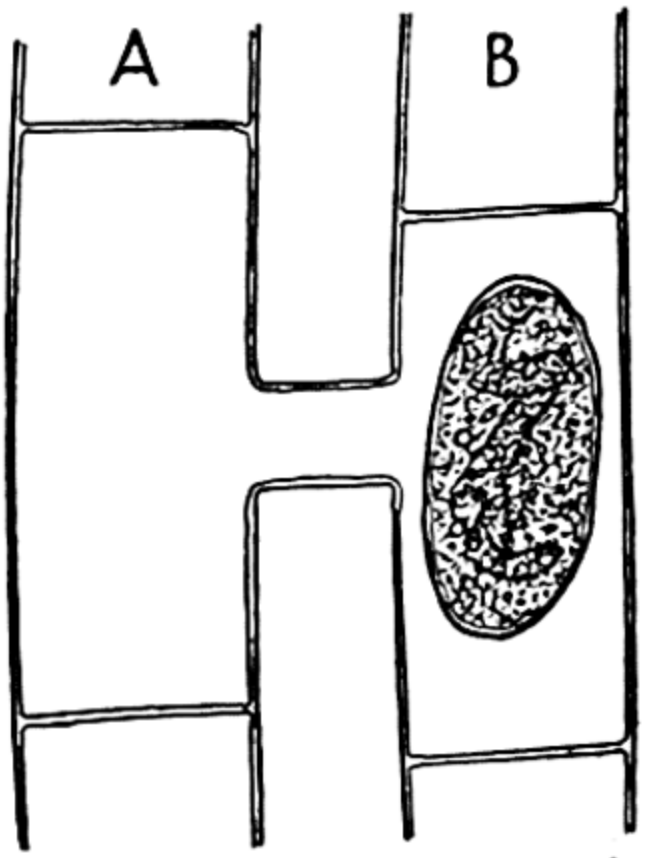
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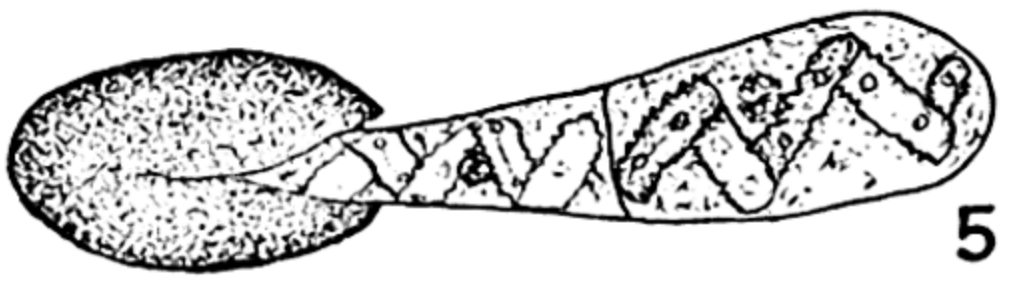
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FIG. 140. CONJUGATION IN SPIROGYRA. 1. Filaments held together by mucilage. 2. Process beginning. 3. Contents of one cell passing into and fusing with those of its partner. 4. Zygote formed. 5. Zygote germinating

alternates with a sexual method involving the fusion of two minute cells (cp. p. 426). One form of the plant (the sporophyte) produces the spores. A very different form (the gametophyte) bears the sex cells. A further discussion of these matters is beyond the scope of this book, but will be found in any standard text-book of botany.

SEXUAL REPRODUCTION

PARENTHOOD. When plants or animals reproduce by any of the various methods just described (binary fission, budding, spore-formation) one organism is concerned in the formation of the new generation; the 'child' is the offspring of one parent only. All such methods are called *asexual*. In *sexual* reproduction two parents share the labour of producing the new life; this is the typical method in all the higher animals and plants. Let us now examine some creatures who reproduce in this way.

CONJUGATION IN SPIROGYRA. We have already studied the cell-structure (cp. Fig. 5) and mode of life (cp. pp. 57 and 77) of this simple, filamentous green alga. How is Spirogyra reproduced? By a simple form of sexual union known as conjugation.

Exercise. Mount some conjugating Spirogyra filaments in water to which a trace of iodine has been added. Examine with a microprojector or under the microscope, try to find various stages in the process of conjugation, and draw suitable ones.

At certain times of the year (chiefly in May and June) Spirogyra plants become attached in pairs by a film of mucilage, and little tubular outgrowths arise on the adjacent cell-walls. These outgrowths, which serve to connect the cells of the two filaments, increase in length and thrust the two plants apart (cp. Fig. 140 (2)). The cross-walls in the middle of each such connexion break down, and open communication is established between the two cells. This process takes place almost simultaneously all up and down the filament.

Changes soon occur in the cell contents. The protoplasts of one plant (*A*) become rounded off and contracted away from the walls; similar changes follow in the second filament (*B*). The contents of the cells of *A* now pass over into and fuse

with the contents of *B* (cp. Fig. 140 (3)). A series of *zygotes*, each produced by the fusion of two cells, is left in *B*, while all that remains of *A* is a number of empty, lifeless cell-walls.

The zygote forms round itself a thick protective wall and passes into a resting condition. In due course it develops into a new plant.

CONJUGATION AND ITS RELATION TO REPRODUCTION. We have called conjugation a method of reproduction; but the process, as we have seen, begins with the fusion of two cells. This is not reproduction; indeed, rather the reverse, for where there were two cells there is now only one. But we find that conjugation is always a preliminary to reproduction. The fusion seems to impart some stimulus to the protoplasm which, sooner or later, leads to active growth. It is obvious that, in Spirogyra, the new plant formed from the zygote is the product of two protoplasmic units of different origin (plants *A* and *B* in the example we have described); in other words, this new plant had two parents.

Conjugation occurs in many of the simpler forms of life, both unicellular and multicellular, in animals as well as in plants. The details of the process vary, but the final act is always the same. Two nuclei fuse to form the first nucleus of the new organism.

CONJUGATION IN MUCOR. We are already familiar with the structure and life-processes of Mucor (cp. p. 200), and know that it usually reproduces by means of asexual spores. Occasionally, however, when two Mucor plants are close together, another form of reproduction may occur. A hypha is put out from each plant and, when the two are in contact, a small cell is cut off from the tip of each (cp. Fig. 141 (2)). The wall separating these two cells breaks down, and their contents fuse to form a zygote. This surrounds itself with a strong, protective wall, and separates from the two parent plants. Given suitable conditions it will form a new growth of Mucor (cp. Fig. 141 (5)).

CONJUGATION AND FERTILIZATION. In every form of sexual reproduction the new organism owes its life to an act of cell fusion, and the life of all the higher animals, and of most of the higher plants (for some exceptions see p. 421), starts in this

way. When the two cells, called *gametes*, are alike in form and function, as they are in Mucor, the process is called *conjugation*. A survey of living creatures shows every conceivable gradation

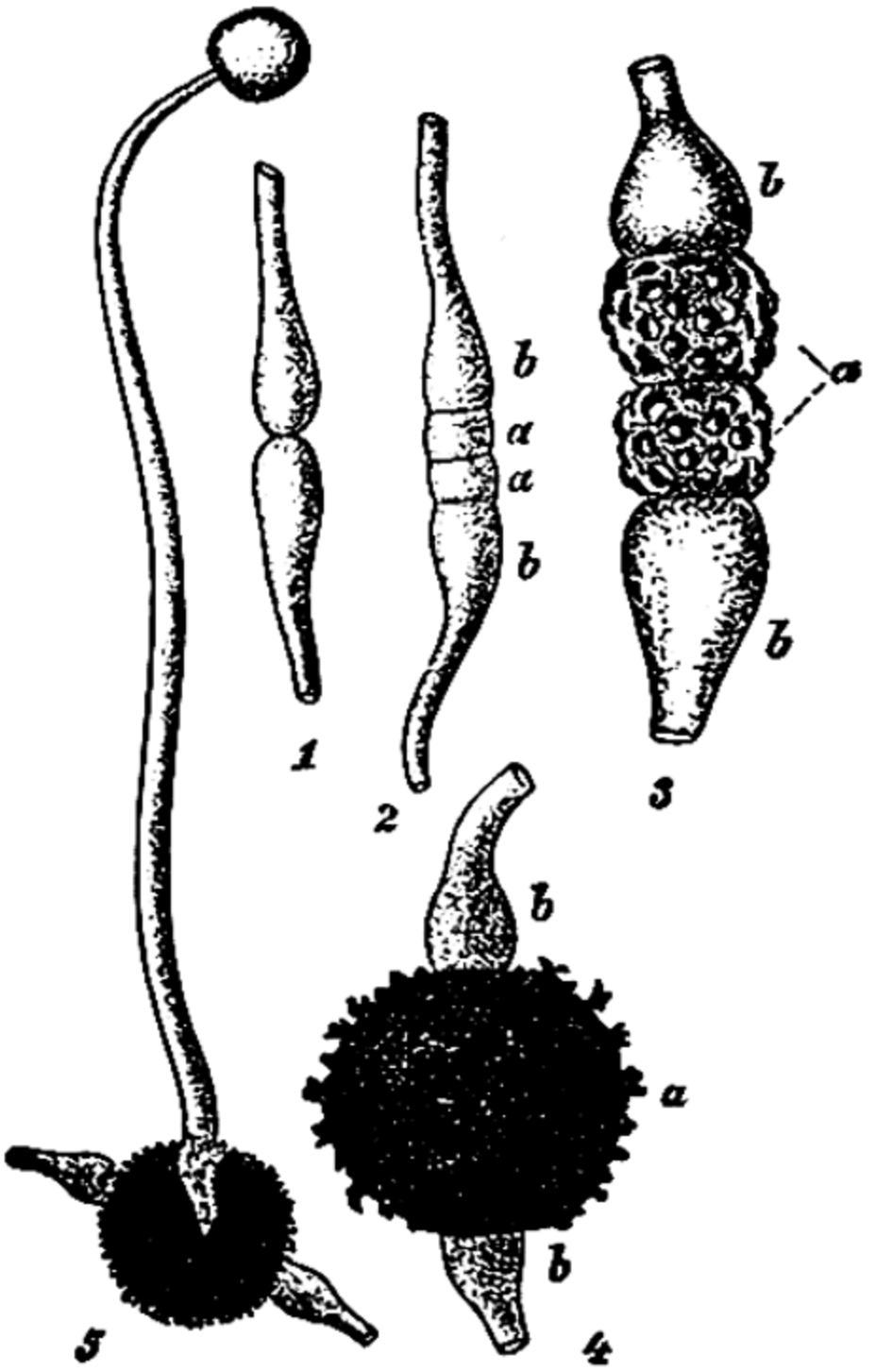


FIG. 141. CONJUGATION IN MUCOR. 1. Hyphae in contact. 2. Conjugating cells; *a*, *a*, cut off. 3. These two cells enlarge and fuse. 4. The zygote. 5. Zygote germinating to form a sporangium containing spores (i.e. asexual reproductive cells)

from this fusion of two exactly similar cells, through such a form as Spirogyra, in which one cell is more active than the other, to types in which the differences between the two reproductive cells become more and more marked. Finally, in all the higher forms, one cell, the female cell (*ovum* or *egg-cell*), is

typically large and inert, containing a store of reserve food; while the male cell (*sperm* or *spermatozoon*) is small and usually active; it has to seek out the motionless egg-cell (ovum) with which it fuses. The reproductive cells of such forms exhibit sexual differentiation.[1]

The fusion of a small sperm with a larger egg-cell is called *fertilization*; a female creature (animal or plant) is one that produces ova; a male, one that produces sperms.

HERMAPHRODITES. In animals the two sexes are usually separate, and often very different in appearance. There are, however, a few hermaphrodite animals, which contain the organs of both sexes, e.g. Hydra, earthworms (cp. Fig. 162), tapeworms (cp. Fig. 50). In the higher (flowering) plants this position is reversed; nearly all these plants are hermaphrodite (monoecious), e.g. pines, buttercups, &c. In a few, however, the sexes are separate, as in palms, willows, some campions, cucumbers, &c. Such plants are called dioecious; the flowers on one plant are staminate and will produce the male cells, those on another of the same species pistillate and will produce and nourish the female cells (cp. p. 448).

FERTILIZATION

Let us now study the exact method of fertilization in a few typical forms.

SEXUAL REPRODUCTION IN HYDRA. Hydra is an hermaphrodite animal which can reproduce both asexually (by budding, cp. Fig. 31) and sexually.

Exercise. Examine under the microscope a hydra displaying ovary and testis. Pressure on the cover-glass may even enable you to see the sperms set free. Sketch the animal and its reproductive organs.

The sex cells of Hydra develop from the small, undifferen-

[1] Even in conjugation, where the fusing bodies look exactly alike, there is probably some differentiation—perhaps a chemical one. In the case of Mucor (p. 426), only certain plants will conjugate with one another. These are termed '+ and − strains', since we do not know of any difference between them other than their readiness or refusal to conjugate.

tiated interstitial cells of the outer layer (ectoderm) of the body wall (cp. p. 149). These cells begin to multiply and a small swelling is produced. This swelling may become a male reproductive organ, or *testis*, in which case a number of sperm mother cells are formed within it; each of these divides into four sperms, the first division of the nucleus being a reducing one (cp. p. 435).[1] The sperm, which is very minute, is a single cell, with a relatively large head containing the nucleus, a narrow neck, and a long, motile tail. It is shed into the water and is quite short-lived.

Another similar swelling of interstitial cells produces the female reproductive organ or *ovary* of Hydra. In this case one central cell enlarges at the expense of its neighbours, actually ingesting them by means of amoeba-like pseudopodia. This central cell is the egg-cell, and it becomes stored with granules of reserve food (yolk). Like the sperm, it undergoes a reduction division.

As it enlarges the wall of the ovary breaks and shrinks back, so that the egg-cell is exposed ready for fertilization (cp. Fig. 31).

FERTILIZATION AND DEVELOPMENT OF THE EMBRYO. An ovary and one or more testes may be found on the same animal, the ovary nearer the base, the testis in the upper region (cp. Fig. 31). In such cases the animal might be self-fertilized, i.e. its egg-cell might be fertilized by its own sperm. But, as these motile sperms are shed freely into the water to which the egg-cells (ova) are also exposed, cross-fertilization of the egg-cell of one animal by the sperm of another will often occur. A sperm penetrates the gelatinous cover which protects the exposed surface of the egg-cell and fuses with it, so fertilizing it. The fertilized ovum remains attached to its parent, undergoing division (cp. Fig. 125); eventually a two-layered embryo is formed. This secretes round itself a horny, protective cover, stops growing, and becomes detached, falling to the bottom of the pond. Here it rests for a time, possibly all through the

[1] By a reduction division the number of chromosomes (cp. p. 43) in the nucleus is halved in preparation for fertilization.

winter, in a dormant condition. Then it becomes active once more and grows into a mature hydra.

Let us now look at the process of fertilization in a more advanced animal, in which the sexes are distinct.

REPRODUCTION AND THE REPRODUCTIVE ORGANS IN THE FROG

We have learned (cp. p. 319) that a frog develops from an egg; we have now to inquire how that egg is produced. Frogs are male and female. The female has two ovaries (cp. Fig. 104), organs which vary tremendously in size at different times of the year. They are largest in winter and early spring, when they contain an enormous number of spherical black-and-white cells, plainly visible to the naked eye. These are the egg-cells or ova.

When they are 'laid' these egg-cells pass to the exterior through two long coiled white tubes, the *oviducts*. While passing down these ducts the familiar gelatinous envelope is secreted round each of them, and thus the egg-cell is converted into an egg. Newly discharged frog spawn is nothing but a mass of these eggs.

Exercises

Examine a dissection of a female frog, opened to display the reproductive organs.

You are given some ova which were removed from the ovary of a frog in winter or early spring. Such ova can be preserved in formalin. Examine and sketch them. Notice the absence of jelly.

Examine a dissection of a male frog, opened to display the reproductive organs.

The male frog possesses paired testes in place of the ovaries of the female (cp. Fig. 104 B).

Each testis is a small creamy-yellow structure, about as large as a maize grain; from it fine tubules pass through the upper portion of the kidney, and from each kidney there is a single duct which leads to the cloaca and so to the exterior (cp. Fig. 104 B). This duct is often called a ureter; a better name is the *vas deferens*. It is not used solely for the excretion of urine (cp. p. 338) but also for the discharge

of the male reproductive cells or sperms. These minute cells are formed in the testis; each consists, as in Hydra, of a head representing the main body of the cell and containing the nucleus, a neck, and a long protoplasmic tail, which is an organ of locomotion. By its aid these small cells (sperms or spermatozoa) can swim through water.

THE LAYING OF THE EGGS. In early spring croaking frogs are to be found in large numbers near the shores of ponds and sluggish streams.

'Motorists drew up beside the main Fareham to London road at Exton yesterday, to allow a great company of frogs to make their way safely from their winter quarters in the meadows to their spawning-ground in the pond opposite.' (*The Times*, 11 March 1936.)

These frogs have just awakened from their long winter sleep, and are preparing for the annual breeding season. Soon they are in pairs; the male is waiting for the female to lay her eggs and as they escape he pours the sperm-laden fluid from his testes over them. When the egg reaches the water its slimy coat absorbs liquid, swells up, and sets, forming the familiar protective jelly (cp. Fig. 98).

FERTILIZATION. A sperm makes its way through this jelly, its nucleus increasing in size as it goes. The sperm nucleus fuses with the egg nucleus, both these having previously undergone a reduction division (cp. p. 435). This fusion is called *fertilization*, and from the fertilized egg a new frog develops (cp. Fig. 98).

Exercise. Examine tadpoles of different ages which have been preserved in formalin, and revise the story of the development of the frog told in Chapter XXV.

Let us now study the process of fertilization in a simple plant.

REPRODUCTION AND THE REPRODUCTIVE ORGANS OF BLADDERWRACK (FUCUS)

This common brown seaweed is a very familiar object on any rocky shore at low tide (cp. p. 83). Its method of reproduction is in many ways similar to that of the frog. The plants

are male and female; the male plants produce tiny motile sperms, the female ones give rise to much larger, dark-green egg-cells. These are shed into the water, being pressed out at low tide by the drying of the plant body. There can be no pairing in these forms, as Fucus plants are incapable of locomotion; but the sperms swim actively, having organs

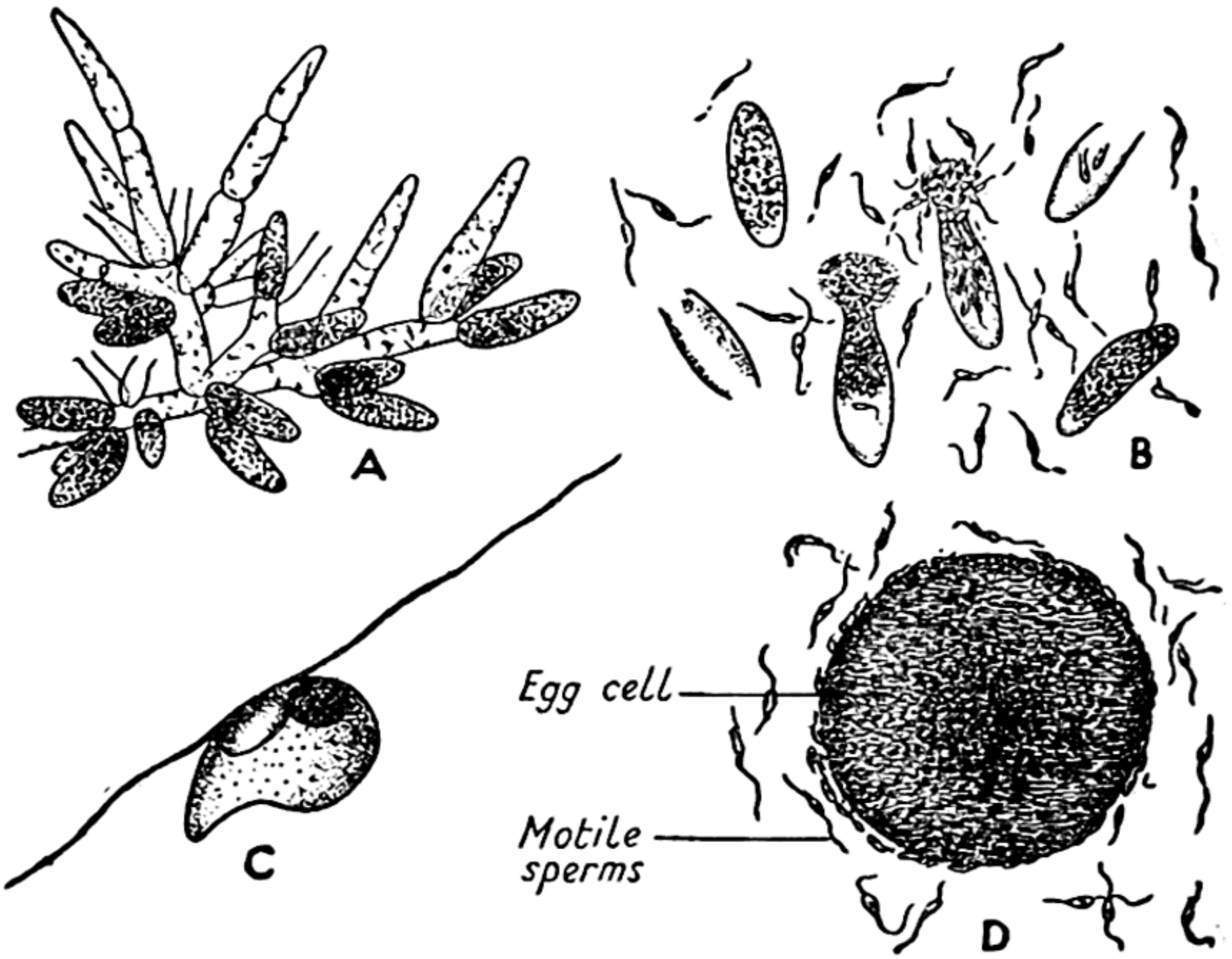


FIG. 142. FERTILIZATION IN FUCUS. **A.** Branching hair from male plant, bearing antheridia. **B.** Sperms escaping from antheridium. **C.** One sperm (very highly magnified). **D.** An egg-cell surrounded by sperms

of locomotion, as have those of Hydra and frog. They are attracted to the egg-cell by some chemical stimulus, and many of them circle round it, causing so much movement in the water that they set the egg in rotation. One sperm enters, passes through the protoplasm of the egg-cell, and fertilizes it, the nuclei fusing; all the other sperms are immediately repelled.

The fertilized egg-cell surrounds itself with a protective wall, and at once develops into a new Fucus plant.

Exercises

Examine a Fucus plant, and draw a portion of the thallus (body); this is not divided into root and shoot systems, and is altogether simpler than that of a flowering plant. Notice, in particular, whether the ends of certain branches are covered with small raised spots, like tiny pin-pricks. Such branches are fertile, the holes leading into pockets which contain the reproductive cells. Examine one of these fertile tips with a lens, and draw it.

Examine prepared sections of fertile branches of male and female bladderwrack (F. vesiculosus), which show the pockets (conceptacles) containing the reproductive cells.

Obtain some fertile Fucus plants direct from the sea, preferably in autumn or winter, and, immediately they arrive, hang them up where they are freely exposed to the air. As they dry, a sticky liquid exudes from the pores on the fertile branches; some plants produce an orange liquid, others one dark green in colour. The last-named liquid is coming from a female plant, and it contains large egg-cells, which, when they first escape, are in groups of eight. Mount some of this liquid in sea-water, and examine these cells under the microscope.

The orange liquid is coming from a male plant, and contains numerous minute motile sperms. Some of this liquid can also be mounted and examined, but the sperms are too small to be seen distinctly with such microscopes as are usually provided in schools. A higher magnification is necessary.

SEXUAL REPRODUCTION IN HYDRA, FROG, AND FUCUS

We see that, different as are the three creatures we have just been studying in appearance, structure, method of feeding, mode of life, &c., yet in all three the processes of sexual reproduction are fundamentally alike; there is always a fusion of two cells to form the first cell of the new organism.

Sexual reproduction is the typical method of reproduction in all multicellular and in many unicellular organisms.[1] The process, being so universal, must be of fundamental

[1] Some very recent work seems to demonstrate sexual fusions even in bacteria.

importance. Let us inquire a little more fully into its significance.

REPRODUCTION AND SPONTANEOUS GENERATION. In every form of reproduction a fragment of parental protoplasm, usually very small (e.g. a spore, a fertilized egg-cell), forms the starting-point of the new organism. We know of no other way in which life can arise. This fact was not realized until quite recent times, and many curious beliefs were current, which were only dispelled by biological investigation. Aristotle, for example, taught that frogs can be generated from slime; Virgil gave an account of the generation of a swarm of bees from the decomposing carcass of an ox; Van Helmont (1577–1644) gave the following instructions for breeding mice: 'Place dirty linen along with a few grains of wheat in a closed receptacle.' Similar ideas were prevalent until the nineteenth century. It was Pasteur who finally proved that even the minutest living things, for example the bacteria and yeasts (cp. pp. 121 and 262), are formed from pre-existing bacteria or yeasts of the same kind, and in no other way. There is no 'spontaneous generation', no formation of living organisms from lifeless matter in the world as we know it to-day.

IDEAS ABOUT THE NATURE OF SEXUAL REPRODUCTION. It was only in the nineteenth century that the actual fusion of egg-cell and sperm was observed; before that time many extraordinary ideas were held about the nature of sexual reproduction. One school, for example, very prominent in the late seventeenth century, maintained that every egg-cell contained a complete organism, fully formed though in miniature, which only needed to be 'fertilized', i.e. to be given suitable nourishment, &c., to make it grow and unfold.

But, if an egg-cell does contain another being 'pre-formed' in this way, it must contain the egg-cells which that being will produce in its turn. You see where the argument led; eventually people were calculating how many eggs Eve's ovaries must have contained, since she was the mother of the whole race of human beings.

We learn once again how dangerous it may be to let our speculations outrun the ascertained facts.

SEXUAL REPRODUCTION, CHROMOSOMES, AND THE REDUCTION DIVISION. Modern research has shown that the essence of sexual reproduction is the fusion of two cells, and especially of the two nuclei involved. Now a nucleus always contains a number of very important structures, the *chromosomes* (cp. Figs. 9, 10), each species having its own special kind, which remain constant, not only in number, but in their form and behaviour, from one generation to the next. Thus the number in our own body cells is 48, in the cells of a frog 24, and whenever a nucleus divides there is a splitting of these chromosomes longitudinally into halves, so that each of the two nuclei proceeding from the division receives one member of every pair (cp. Fig. 9).

Preceding the formation of the sex cells, however, a special kind of nuclear division takes place, the so-called *reduction division*, by which reproductive cells are formed which contain half as many chromosomes as the body cells. Thus, when the sperms of a frog are developing, the 24 chromosomes of the so-called 'sperm mother cells' become segregated into two sets of twelve; there is no longitudinal splitting, they separate as *whole chromosomes*, and each sperm receives a half-set (12) only. The same thing happens in the formation of the egg, and one great result of fertilization is that the original number is restored. The first cell of the new organism has its full complement of chromosomes once more, half having been derived from one parent, half from the other. This fact is probably of great importance in heredity.

Although the above facts are now well established, and we know something about the actual process of reproduction, a very great deal still remains obscure. Each fertilized egg contains within itself such definite and directed powers of growth and development that one speck of protoplasm grows into an oak tree, a second into an earthworm, a third into a human being.

The question at once arises, why do these three egg-cells develop so differently? We know very little about the forces at work. This is one of the biological problems at which present-day scientists are working, and gradually a little knowledge is accumulating to throw light on these difficult matters.

HEREDITY. We know that the child tends to resemble its parents; this is what we mean by heredity. We can now state that as a rule this result is somehow achieved by the passing on of a fragment of parental protoplasm, with its nucleus and chromosomes. 'Like begets like' primarily because the offspring is literally 'a chip off the old block', i.e. formed from the same kind of protoplasm.

Further, we know from observation and experiment that, where there is one parent only, as in all asexual processes of reproduction, the resemblance between parent and offspring is extremely close. For this reason plant-breeders, when anxious that their new plants shall be 'true to type', i.e. exact replicas of the parent organism, resort to some form of asexual reproduction, either natural (from tubers, runners, rhizomes, &c.) or artificial (from cuttings, graftings, &c.) for the replenishment of their stock (cp. p. 421).

When any creature has two parents it is not exactly like either, but owes (roughly) half its characters to the one parent, half to the other; these characters the parents received in turn from the grandparents; some may even be 'latent', i.e. without obvious effect, in the parent, and yet be passed on to the child, so that in certain features that child resembles one of its grandparents, rather than its immediate parent. It seems certain that this passing-on of hereditary characters is closely connected with the passing-on of the chromosomes.

THE SCIENTIFIC STUDY OF HEREDITY. We are gradually collecting knowledge about the laws of inheritance. This is done partly by experiment, two related plants or animals being crossed, and the results of the union carefully examined. A great pioneer in this field was MENDEL (1822–84), abbot of the monastery of Brünn, who investigated the inheritance of pairs of contrasted characters (e.g. tallness versus shortness, yellow seeds versus green seeds, &c.) in certain cultivated plants, particularly edible peas (cp. p. 464).

To study heredity in the human race we rely chiefly on statistics, collecting figures as to how many tall parents have tall children, how many geniuses have specially able children, what proportions of mental defectives have mentally defective

children, and so on. A large mass of knowledge is gradually becoming available which may have very important consequences in the near future (cp. p. 522).

BOTH PARENTS CONTRIBUTE EQUALLY TO THE INHERITANCE. One very striking fact remains to be mentioned. Although, as a rule, the male parent only contributes a minute sperm to the new life, the female egg-cell being very much larger, nevertheless the two exert an equal influence on the inheritance. Black Andalusian fowls, mated with similar black cocks, produce black offspring, while from a mating of white birds white offspring result. When a black bird is mated (crossed) with a white one, the offspring are blue, and this is true whether the hen is black and the cock white, or vice versa.

Such an experiment illustrates the Mendelian method of investigating the laws of heredity, and from it and others like it we have learned that the influence of the two parents is nearly always equal.

THE EFFECTS OF SEXUAL REPRODUCTION. Let us now examine the chief results that follow from this method of reproduction.

i. The process is obviously very economical. Large numbers of offspring can be started, often simultaneously (e.g. in the frog), with comparatively little drain on the parent organism.

ii. The entrance of the sperm seems to stir up the egg to greatly increased activity. It has been shown in many cases, for example, that the entry of the sperm very greatly increases the rate of respiration of the egg-cell.

iii. The mingling of two strains, and especially of two sets of chromosomes, provides an opportunity for variation. Sexually produced organisms are never exactly like either parent, but share the characters of both. It seems likely that the great advantage of the sexual, as opposed to any asexual, process is that it makes such variation possible.

iv. At the same time the sexual method of reproduction exerts a conservative influence, helping to keep the racial characters fixed and constant.

That it can, at one and the same time, promote both variation and fixity seems at first sight a paradox. But experiments

show that only the gametes of closely related organisms will fuse. A cat's egg-cells, for example, cannot be fertilized by the sperms of a dog or a rabbit. Hence cats remain cat-like; the type is fixed and fairly constant. Nevertheless, within the group, there is much crossing of tabbies with black, white, ginger, and other coat colours, of 'common' cats with Persians, Manx, Chinchillas, and other special strains.

It is difficult to predict the exact result of any such cross, especially when the parent animals are of mixed ancestry. The sexual process may be compared to the making up of one new and complete pack of cards from two complete 'parent' packs. Roughly, equal numbers of cards are selected from each of the two original packs (cp. p. 435), but usually it is quite impossible to say from which of the packs (total parental characters) any particular card (set of inherited characters) in the new pack (characters of the offspring) will be drawn. Eye-colour, for example, is a definite inherited character, but we cannot usually predict whether the offspring will resemble its male or its female parent in this respect.

Animal breeders, to whose activities we owe the fleetness of modern race-horses, the high milk-yield of modern cows, the intelligence of our sheep-dogs, &c., obtain the characters they require by breeding only from those animals who possess that character in a marked degree, i.e. by a process of selection. DARWIN showed what great results can be obtained in this way; all the races of fancy pigeons, for example, have been produced by selection from the rock-dove (*Columba livia*). You should consult Darwin's great book.

THE WIDER RESULTS OF SEXUAL REPRODUCTION. The effects of sexual reproduction do not end with the consequences summarized in the preceding paragraph. Much of the richness and variety of life is closely connected with this process. In the first place, eggs and sperms must be brought together; in subsequent chapters we shall learn how this end is attained in various groups of plants and animals, and see how profoundly this necessity affects the way of life of these creatures.

Secondly, many organisms do not abandon the fertilized egg at the very beginning of its existence, as do both Fucus and

frog. Even in these forms there is some slight provision for the new generation, in the form of a store of food. It is this necessity for food-storage which makes the egg-cell large and passive, and entails as a further consequence that the sperm shall be active enough to reach the egg. We may regard this storing-up of food for the new life as a form of parental care—the only form of such care bestowed by a Fucus or a frog on its offspring. But in other organisms we find many different methods of protecting and nourishing the new life during its early stages of existence, until we come to the care lavished on their young by birds and mammals. As a rule the higher the creature in the scale of life, the greater the protection given to the new generation. This care of the young gives the animal its first training in altruism. It has led, in the course of evolution, to the development of those instincts which make the individual ready to subordinate its own purely selfish interests for the good of the group, be it just the immediate family, or those larger groups—herd, pack, flock, school, tribe, or nation. In the following chapters we shall study many examples of this parental care.

QUESTIONS ON CHAPTER XXXI

1. Give an illustrated account of the structure, mode of life, and methods of reproduction of (*a*) yeast, or (*b*) Mucor.

2. What do you understand by conjugation? Describe with the aid of labelled diagrams how this process is carried out in (*a*) Spirogyra, and (*b*) Mucor. What is the chief difference between conjugation and fertilization?

3. Give instances, and a short illustrated account, of the following natural methods of reproduction, (*a*) simple division, (*b*) budding, (*c*) development from an egg-cell. (L.G.S.)

4. Make labelled drawings to illustrate the essential features of plants which propagate vegetatively by means of (*a*) runners, (*b*) suckers, (*c*) rhizomes. Name the examples you select to illustrate your answers. (C.L.)

5. What are the essential features of reproduction? Illustrate your answer from any animal types with which you are acquainted. (C.L.)

6. Compare and contrast the structure, method of feeding, and reproductive processes in Amoeba and yeast.

7. Describe, with the aid of large, clear, labelled diagrams, the reproductive organs of the frog, and give a brief account of the method of reproduction.

8. Describe the various types of reproduction with which you are acquainted, mentioning examples in each case. Point out which of these types you regard as most beneficial to the organism, giving your reasons. (L.G.S.)

9. What do you understand by (*a*) asexual, (*b*) vegetative, (*c*) sexual reproduction? Give a detailed, illustrated description of each of these methods, as it occurs in any one organism, plant *or* animal, which you have studied.

10. Write a short account of the reproduction and spreading of bacteria. (Ox. & C.)

11. Write a short essay on reproduction. (L.G.S.)

12. State concisely the difference between sexual and asexual methods of reproduction. Describe the reproduction of Spirogyra in detail. (Ox.L.)

13. Give an account of the various ways in which Hydra multiplies. (C.L.)

14. Distinguish between five of the following:—secretion and excretion; sexual and asexual; living and non-living; development and heredity; cilia and flagella; gamete and zygote; complete and incomplete metamorphosis; ectoderm and endoderm. (Ox.L.)

CHAPTER XXXII

REPRODUCTION IN FLOWERING PLANTS

THE *flower* is the specialized shoot which bears the reproductive organs in all the higher plants. Most people believe that the seed is the starting-point of a new plant, but this is not the case.

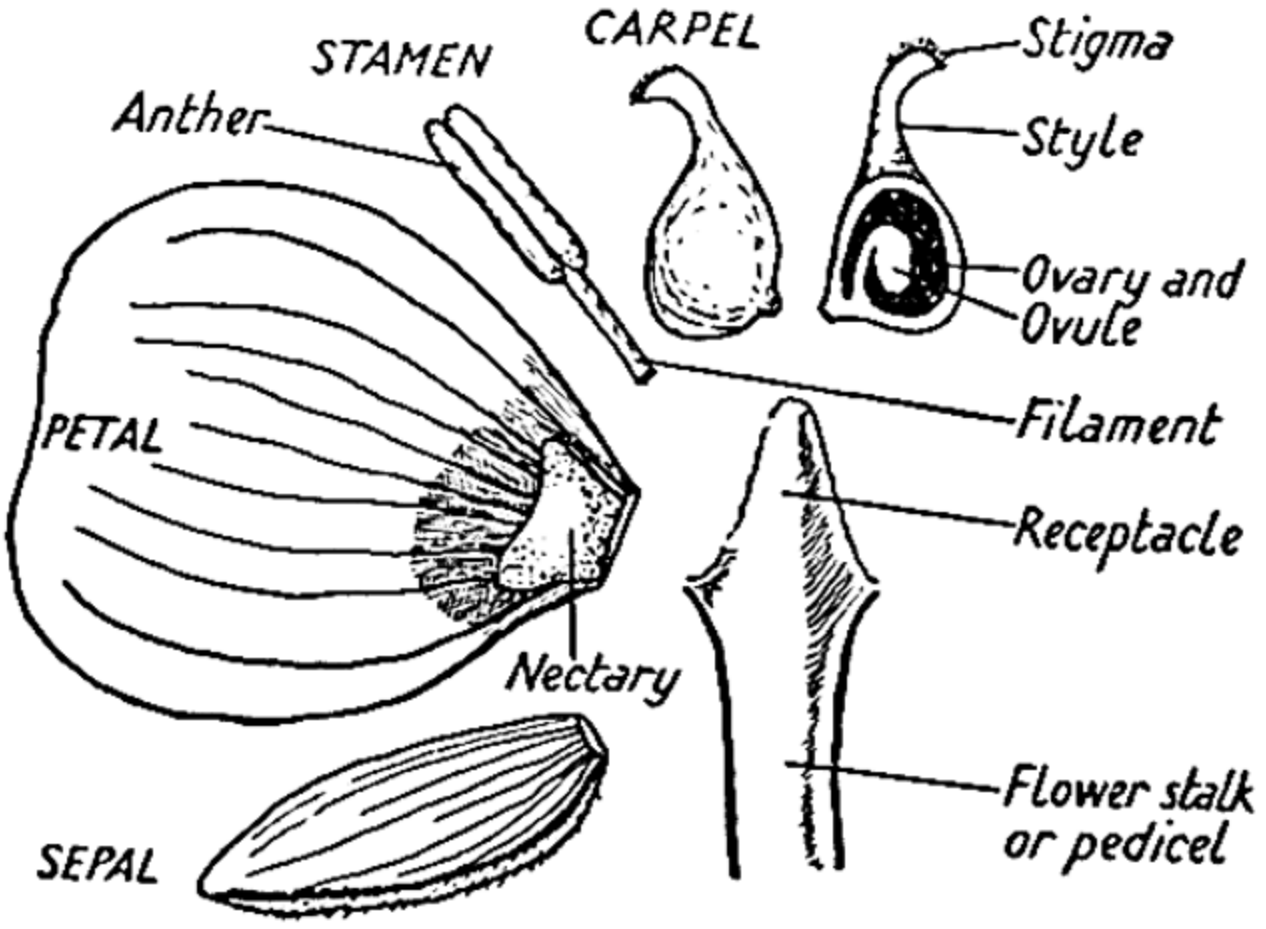


FIG. 143. Parts of a buttercup flower

Inside every seed there is a well-developed embryo plant in which the root and shoot systems are usually plainly discernible (cp. Figs. 17, 106, 107). It is by means of the flower that the parent plant forms, feeds, protects, and generally serves these embryos until they are ready to begin their independent existence. If you look at any fading flower you will see that one part of it, the gynoecium or pistil, is enlarging and forming the fruit, and inside this fruit are the developing seeds. The plant is a good parent, nourishing and protecting its embryos for a long time before they are finally cast adrift.

A *complete or perfect flower* consists of four distinct organs, all arranged on a central axis, the receptacle. These are:

(1) The *androecium* and *gynaecium*, which are known as the

essential organs for reasons which will appear later. The androecium is the collective name for all the stamens of a flower, the gynaecium for all the carpels.

(2) The *calyx* and *corolla*, which are known as the accessory organs. They are not essential to seed-formation, though they aid the reproductive process in many ways. These lie outside the stamens and consist of leaf-like structures, the calyx being formed of sepals and the corolla of petals. The corolla is usually brightly coloured and is the most conspicuous part of the whole flower.

Exercise. Examine any perfect flower, such as a buttercup, a primrose, or a dead-nettle, and identify the organs described above.

Many flowers are incomplete, some even consisting of stamens only, others only of carpels (e.g. staminate and pistillate flowers of hazel, willow, poplar, &c.). These flowers occasionally grow on different plants.

Stamens and carpels are both necessary for seed-production. The carpels produce ovules, and in each ovule there is an egg-cell which, if fertilized, will develop into a new plant. The stamens form pollen grains, from which the male cells which fertilize the ovules arise. That stamens are necessary for seed-production can be shown by the following experiments.

Experiment 105. With a pair of fine forceps remove the stamens from some newly opened flowers. Be sure that the stamens have not yet dehisced. Cover the flowers loosely with bags of fine muslin or paper, to prevent pollen reaching them from other flowers.

Flowers so treated never make fertile seeds (there are a few exceptions (p. 471)). To show that this is due to lack of pollen, and not to the injury caused by removal of the stamens, take off the stamens from another group of similar flowers, but do not shield them by bags. If left open to insect visits, some of them, at least, will make seeds.

STRUCTURE OF A STAMEN.

Exercises

Remove stamens both from the buds and the open flowers of buttercups, tulips, &c., and sketch them to show their structure.

With a sharp razor cut a transverse section of the head (anther) of a young stamen, and examine with lens or microscope. Mount

some of the pollen grains which you find inside the head, and examine them under lens, microscope, or microprojector.

The stamen consists of a thin stalk or filament, and a larger

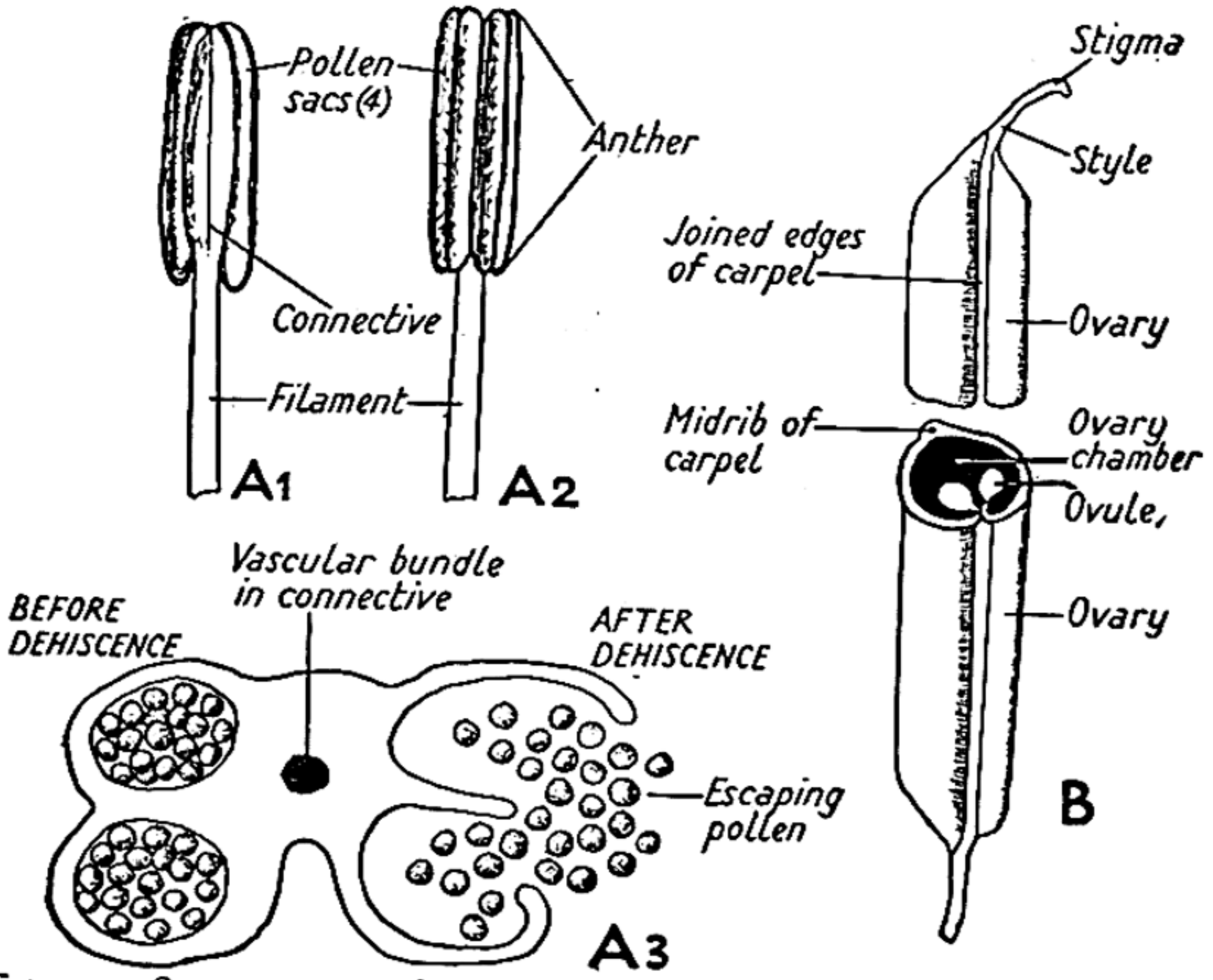


FIG. 144. STRUCTURE OF STAMEN AND CARPEL. **A1, A2.** Two views of a stamen (×3). **A3.** Transverse section of the anther (×10). **B.** A single carpel

head or anther. The anther is usually made up of two anther lobes united by a connective (cp. Fig. 144 A). Each lobe encloses two pollen-sacs which contain numerous minute pollen grains. In older flowers we find that the anthers have opened (dehisced), usually by a longitudinal slit, so that pollen is escaping.

STRUCTURE OF THE GYNAECIUM.

Exercise. Examine and sketch the gynaecium of the sweet-pea or gorse, buttercup or king-cup, bluebell or hyacinth, and violet or pansy. Cut transverse sections of the ovaries of each type; examine with a lens or microprojector and make an enlarged drawing.

A gynaecium or pistil is the central organ of the flower, being formed at the apex of the receptacle. It is made up of one or more carpels, structures which bear some resemblance to small leaves. The nature of a *carpel* is best seen by examining the pistil of a pea or gorse flower, which is formed of one carpel only. It is a leaf-like structure, folded along its midrib (or dorsal suture), and joined by its two edges (the ventral suture) to form a closed chamber, the ovary, within which the ovules arise. Plants in which the ovules are thus enclosed are called Angiosperms. Gymnosperms are seed plants in which the ovules are 'naked' on the carpel. In Angiosperms, where the ovules are enclosed from the beginning in the ovary chamber, the tip of the carpel is prolonged into a style which ends in a stigma (cp. Figs. 144 B and 145). The surface of the stigma is specialized for the reception of pollen grains, being often rough, hairy, or sticky, thus playing an important part in the reproductive process.

STRUCTURE AND DEVELOPMENT OF THE OVULE AND EGG-CELL. An ovule begins as a small outgrowth from the placenta (edge) of the carpel, called the nucellus. Soon two protective coverings (integuments) arise from its base and grow up round it. They do not completely enclose the nucellus; a minute hole, the micropyle, is left which gives access to it.

In the centre of this nucellus there develops a large space, the *embryo-sac*; when the ovule is ready for fertilization it contains eight free cells, which all contain half the usual number of chromosomes (cp. p. 435). One of these is particularly important; this is the *egg-cell* or female reproductive cell, which after fertilization will give rise to the new embryo plant. The egg-cell is usually found at the end of the embryo-sac nearest to the micropyle, and it is through the micropyle that the tube which brings the male cell will enter (cp. Fig. 145).

FERTILIZATION AS AFFECTED BY LIFE ON LAND. In studying the processes of fertilization described in the last chapter, we often found that the egg-cells were expelled into water, where they were left to take their chance of fertilization by a motile sperm. This had also been shed into the water, and was provided with an organ of locomotion, by which it could move

and reach the egg-cell, to which it was attracted by some stimulus, probably a chemical one.

This method of fertilization is admirably adapted to the needs of creatures who lay their eggs in water; there is no protection of the egg-cell, as a rule, and apart from the storing up of reserve food (yolk) in the egg, there is little parental care.

But creatures living on land could not survive under such conditions. A fragment of naked and unprotected protoplasm would be in continual danger of drying up, if shed on the land; hence, in such organisms, we find many methods by which their egg-cells are protected; in nearly every case they are retained, as they are in flowering plants (cp. Fig. 145), within some chamber or cavity where the danger of drying is avoided. This protection of the egg-cell hinders the free access of the sperm; how is the male cell to reach the egg-cell, when it can no longer swim about in water to find it?

We shall find, as our work proceeds, that this problem has been solved in many different ways, the processes leading to fertilization being very different in different organisms. In flowering plants two separate stages are involved, the first of which is known as *pollination*.

POLLINATION. A ripe pollen grain is a small cell enclosed in a rather thick, two-layered wall, the outer portion of which is often roughened and covered with raised points and ridges (cp. p. 456). This pollen grain has no power of independent locomotion; nevertheless it must reach the stigma of the gynaecium if the ovules are to be fertilized. The pollen is set free when the anther dehisces (cp. Fig. 144 A3), and is then ready to be transferred. The act of transference of a pollen grain and its deposition on the stigma is called pollination.

Sometimes a flower is so constructed that its stigma becomes covered with its own pollen; look at a buttercup or a bluebell flower, and you will see this happening; the stigmas are surrounded by the dehiscing anthers. Such a flower is *self-pollinated*, and unless it is self-sterile, i.e. incapable of being fertilized by its own pollen, as often happens, this self-pollination may lead to self-fertilization.

It is, however, a well-known fact, long recognized by plant and animal breeders, that all forms of *inbreeding* may lead to a weakening of the strain. Even uncivilized man often realizes the truth of this law. This has led to the development of many tribal customs designed to prevent marriage between close relatives. Darwin carried out many experiments on this subject, investigating the differences between the action of pollen from the same and from another similar flower.

He showed conclusively that

'wherever plants which are the offspring of self-fertilization are opposed, in the struggle for existence, to the offspring of cross-fertilization, the latter have the advantage'

for

'More numerous seeds and more vigorous offspring are obtained by the application of pollen from another flower than by self-fertilization.' (Charles Darwin, *Origin of Species*.)

In view of these experimental results (cp. Chapters XXXIII and XXXIV) it is not surprising that we find much cross-pollination among flowering plants, the pollen being transferred by various moving agents, such as wind, water, insects, &c., from one plant to another.

When pollen is carried (usually by some external agent) from one flower to another of the same kind, such flowers are *cross-pollinated*. There is, as we shall see later, a very close relationship between the way in which its pollen is transferred and the shape, structure, and colour of a flower.

FERTILIZATION. When once pollen has been deposited on the stigma the second stage follows without any further external aid. The grain, stimulated by a sticky fluid secreted by the stigma, sends out a pollen-tube which grows down through the style. Eventually it reaches the ovary, enters the ovule, usually by the micropyle, and reaches the egg-cell (cp. Fig. 145). A channel is thus prepared down which the male fertilizing cell can pass.

Each pollen grain forms two male cells. (As the result of a previous reduction division in the pollen mother cells the pollen grain itself and all cells formed by it have their chromosome

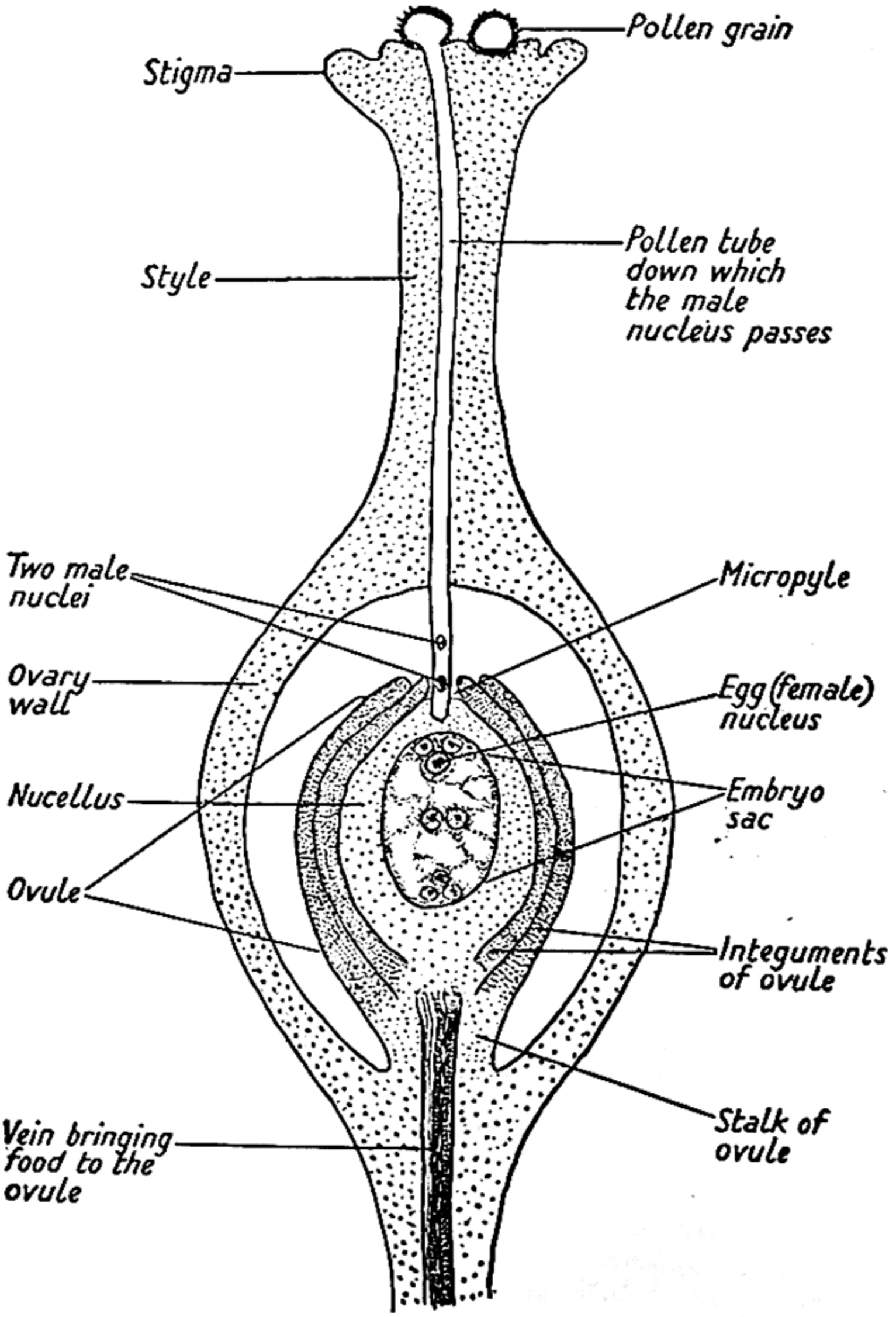


Fig. 145. Ovule at time of fertilization (diagrammatic)

number halved.) The male cells travel down the pollen tube, and one of them fuses with the egg-cell. Fertilization is thus achieved, although the cells which fuse are not set free, but remain protected all through the process.

From the fertilized egg-cell a new plant develops.

Exercise. Place a few pollen grains of a bluebell in a 10 per cent. sugar solution in a watch-glass and keep warm. In an hour or so slender threads can be seen growing out of some of the grains. These are the pollen tubes.

Experiment 106. Place the stigmas of about a dozen bluebell flowers in a test-tube, add Fehling's solution, and test for sugar. We see that the stigmas provide a sugary fluid which helps to attach the pollen grains, and to feed the developing tubes.

DEVELOPMENT OF THE SEED AND OF THE EMBRYO PLANT. The changes in the ovule that follow upon fertilization, by which it becomes a seed, may be summarized as follows:

Parts of the ovule	*Corresponding parts of seed*
1. Integuments	1. Testa of seed
2. Micropyle	2. Micropyle of seed
3. Funicle (stalk)	3. Funicle of seed
Egg-cell	Embryo plant
Embryo-sac and nucellus	The cavity of the embryo-sac outside the developing embryo becomes filled with food-storing cells (endosperm),[1] and eventually so enlarges that it encroaches on the nucellus (cp. Fig. 165).

DEVELOPMENT OF THE FRUIT. While the ovules are ripening into seeds, the ovary wall grows, thickens, and undergoes many changes, forming the *pericarp* of the fruit. The stigma and style usually wither and fall off, and the fruit is left with its contained seeds.

There is great variety in the structure of fruits. The pericarp is often brightly coloured and succulent as in the plum and tomato; it may be dry and brittle, as in a snapdragon; sometimes it is hooked,

[1] In some seeds (*endospermic*) the ripe seed still has reserve food stored in the endosperm. In others (non-endospermic) the embryo absorbs all the endosperm *before* the seed is ripe (cp. p. 348).

as in cleavers; sometimes provided with a wing (e.g. sycamore) or plume of hairs (e.g. dandelion). In these and many other ways to be discussed later the pericarp often becomes an organ which aids in the dispersal of the seeds (cp. Chapter XXXV).

THE FLOWERING PLANT AS A PARENT. We have learned that there is, in flowering plants, a process of sexual reproduction which is admirably adapted to life on land. There is no exposure, either of the gametes (reproductive cells) or of the young embryo. Both are carefully protected through all the processes of fertilization and early development. The pollen tube serves to bring male and female cells together, while, after fertilization, the new plant develops within the body of its parent, enclosed in various protective envelopes—testa, ovary wall, and sometimes receptacle as well—all these being parts of the parental organism (cp. Fig. 165).

Further, the embryo is nourished by the parent for a considerable time, food reaching it through the vascular bundle of the ovule. The amount supplied is in excess of its immediate needs, and a store is laid down which it can draw upon when its connexion with the parent is finally severed. This is the food used for germination (cp. pp. 347–58).

Finally, when the inevitable separation from the parent takes place, there is often some dispersal mechanism by which the passive young plant is scattered to 'fresh fields and pastures new'.

Flowering plants represent the culmination of plant life, and they have evolved a high form of parental care. There is a very analogous series of events among the highest animals, the mammals. They, too, enclose and protect the embryo, and nourish it both before and after its birth, i.e. the beginning of its independent existence. We shall return to this subject in Chapter XXXVI. A high level of development is always accompanied by a high degree of parental care. This is one of the fundamental facts revealed by a study of biology.

QUESTIONS ON CHAPTER XXXII

For questions on this chapter see questions to Chapter XXXIV,

CHAPTER XXXIII

SOME FLOWERS AND THEIR POLLINATION MECHANISMS

LET us now examine the structure and method of pollination of a few common flowers.

THE BUTTERCUP. Many species of buttercup grow in Britain, of which the bulbous buttercup, the meadow buttercup, and the creeping buttercup are the commonest. Examine a flower of any one of these species.

Exercise. Remove the parts of the flower, one by one, and sketch the various organs. Then cut a flower longitudinally down its middle and notice the shape of the receptacle and the position of the various organs on it.

The buttercup is a perfect flower (cp. Fig. 143); it consists of:

i. A conical receptacle, which represents the specialized apex of the flower-stalk; from this all the organs of the flower arise.

ii. A calyx of 5 completely separate, 'free' sepals. These are hypogynous, i.e. they arise from the receptacle below the gynaecium (cp. Fig. 153).

iii. A corolla of 5 free, hypogynous yellow petals, which alternate with the sepals; each has a pocket-shaped *nectary* at its base.

iv. An androecium of numerous free, hypogynous stamens, arranged spirally on the receptacle. These dehisce so that the pollen is shed towards the outside of the flower, i.e. they are extrorse.

v. A gynoecium of numerous carpels, each consisting of separate stigma, style, and ovary. Within each ovary is a single ovule. These carpels are free from one another (apocarpous). The whole gynaecium is superior, i.e. it arises from the top of the receptacle and above the other organs of the flower.

DIAGRAMS WHICH SHOW THE STRUCTURE OF THE FLOWER. When an architect or engineer wants to make a design clear he

often constructs two diagrams, a horizontal or ground plan, and a vertical elevation (or longitudinal section), of the building or the engine he has in mind. Similar diagrams are very useful in making clear the structure of a flower. We call them *floral diagrams* and *longitudinal sections*. Let us learn how to construct these for a buttercup.

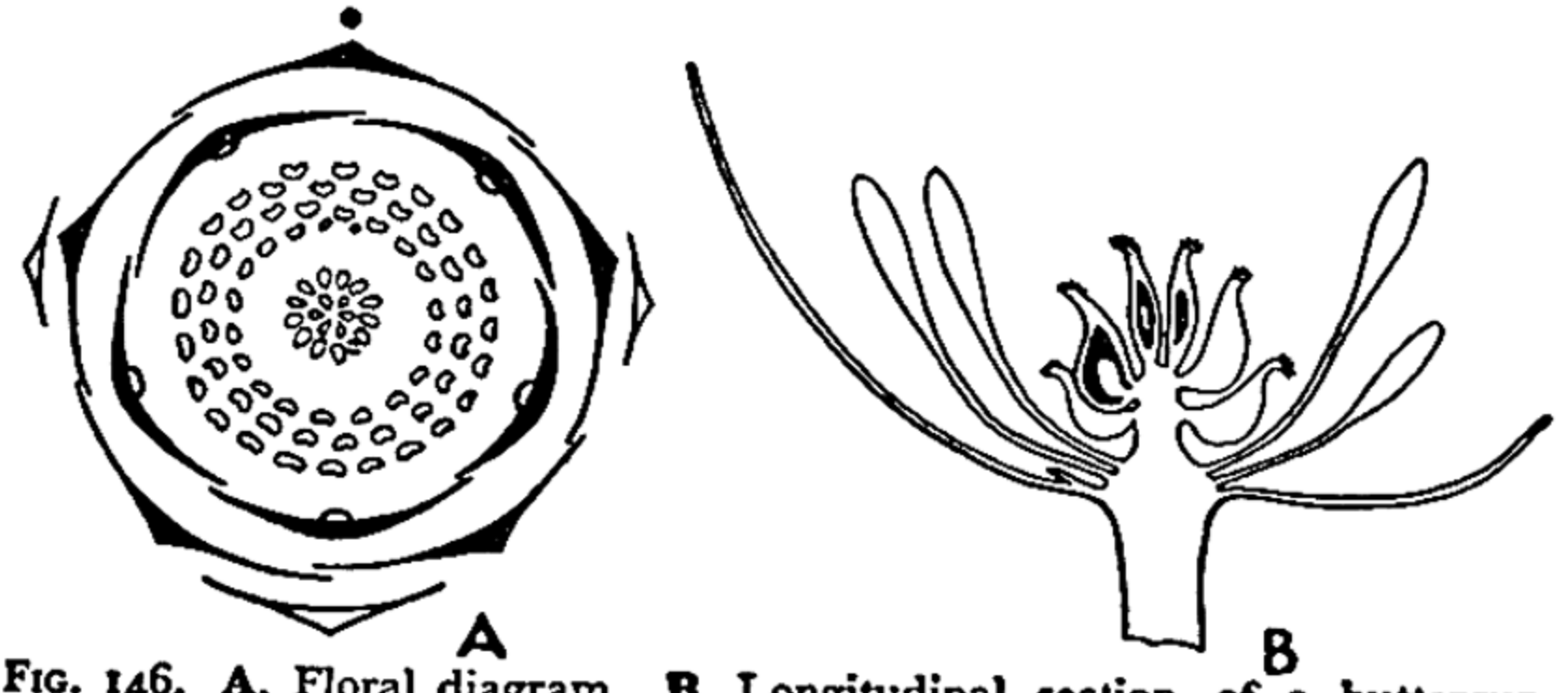


FIG. 146. **A.** Floral diagram. **B.** Longitudinal section of a buttercup flower. (After Yapp)

Exercises

To construct a floral diagram. The foundation for these diagrams is always a series of concentric circles. Each circle will represent one whorl (or ring) of floral leaves, the outermost circle representing the lowermost whorl. The stem from which the flower-stalk arises is represented in the diagram by a dot; the leaf (called a bract) in the axil of which the flower develops is represented by a bracket. We now insert the whorls in the diagram, taking care to place them in the right relationship to axis and bract.

In a buttercup we insert its sepals on the first circle, making them quite separate; 5 free petals on the next, which alternate with the sepals; then numerous stamens with anthers directed outwards (since their dehiscence is extrorse). In the buttercup the stamens are not in circles or whorls, as in most flowers, but are arranged spirally on the receptacle. Inside the innermost circle we make a drawing of the gynaecium as seen from above.

Such a diagram shows at once the number of whorls of which any flower is composed, the number of organs in each whorl, whether

they are joined to each other or free, and their arrangement relative to one another.

To construct a longitudinal section. This is a drawing of an imaginary slice, having no thickness, cut longitudinally through the centre of the flower. It is constructed from the half-flower, by drawing only the cut surfaces. Such diagrams show clearly the shape of both the receptacle and the flower, and illustrate the position of the various organs on the receptacle. Cut a buttercup flower longitudinally through the centre—it is wise to start cutting at the lower, stalk end. Examine the half-flower carefully, and compare it with the longitudinal section drawn from it (cp. Fig. 146 B).

By such sketches and diagrams we can make clear the most important features in the structure of any flower. The salient characters can be expressed shortly by a *floral formula.* The buttercup formula is: $K_5\, C_5\, A\, \infty\, \underline{G^{\infty}}$, where K = calyx, C = corolla, A = androecium, and G = gynoecium, while the symbol ∞ is used to indicate that the parts are numerous. The line beneath the last symbol shows that the gynoecium is superior.

Pollination of the buttercup. How does buttercup pollen reach the stigmas of the buttercup flower? If we examine these flowers from day to day we find that they are somewhat *protandrous*, i.e. most of their stamens open (dehisce) before their stigmas are ready to receive pollen. There is only a short period when male and female stages overlap; during this time self-pollination is possible (cp. p. 445).

But the flower makes nectar and abundant pollen. Both these substances are much sought for by insects, the nectar (a solution of sugar in water) supplying them with carbohydrate, and the pollen with protein food. Its bright colour and attractive scent make the flower conspicuous, and we may often see insects flitting over a buttercup meadow and alighting on the flowers. These are shallow, and an insect need only have a short proboscis (cp. p. 460) for it to reach the pocket-like nectaries, long-tongued flies (hover flies) and small bees being the buttercup's most frequent insect visitors.

If you will consider the path of an insect probing for nectar you will see that the extrorse dehiscence of the stamens brings the escaping pollen directly in the way of the insect visitor.

It gets covered with it, and quite unconsciously carries it from flower to flower. In this way there is much cross-pollination by insect agency, though, as we have seen, self-pollination is not entirely excluded. These pollination mechanisms should be studied out of doors.

The buttercup fruit and seed.

Exercise. Examine and sketch (*a*) the pistils of fading buttercup flowers, (*b*) ripe fruits. The fruit is a collection of small nuts or

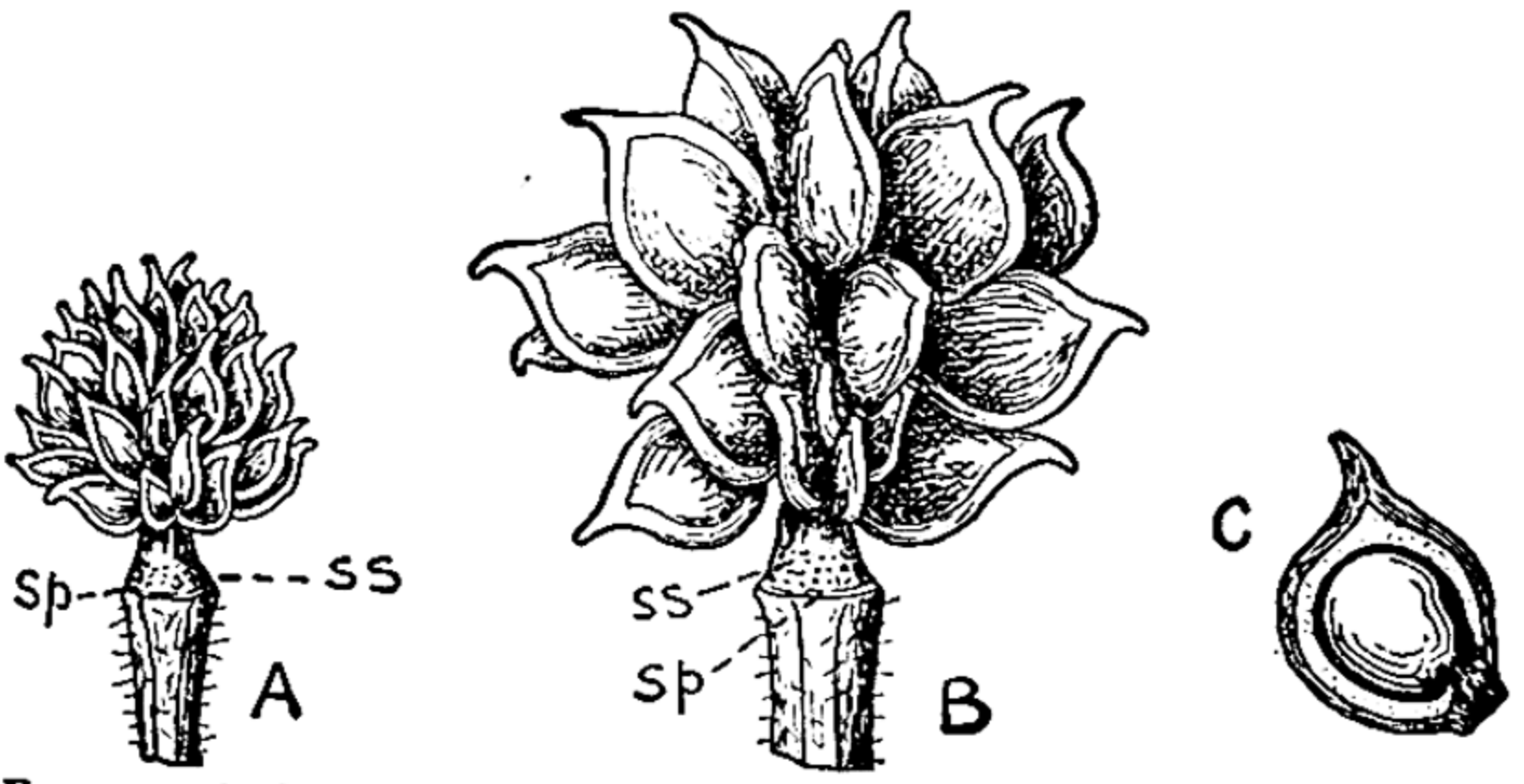


FIG. 147. **A.** The apocarpous gynaccium of the buttercup flower. **B.** The fruit. **C.** A single achene and its contained seed. *ss*, scars of stamens; *sp*, scars of sepals

achenes. Soak a ripe fruit overnight in water, and dissect out the small seed. It is endospermic, and within the white endosperm you may be able to find the embryo plant with its two tiny cotyledons and more conspicuous radicle.

THE HAZEL, like many of our trees and shrubs, has small inconspicuous and incomplete flowers. They appear very early in the year, before the foliage leaves have unfolded. The flowers are of two kinds, staminate and pistillate, both sorts being produced on the same plant.

Each *staminate flower* arises in the axil of a bract, and consists of two small scales and of four stamens (cp. Fig. 148 C).

These flowers are arranged spirally on a drooping axis; the whole structure is often called a 'lamb's tail'. This is a simple type of *inflorescence* (flower grouping) known as a catkin, consisting of unstalked, unisexual flowers. In the hazel it is formed in the autumn and elongates very rapidly in the following February or March.

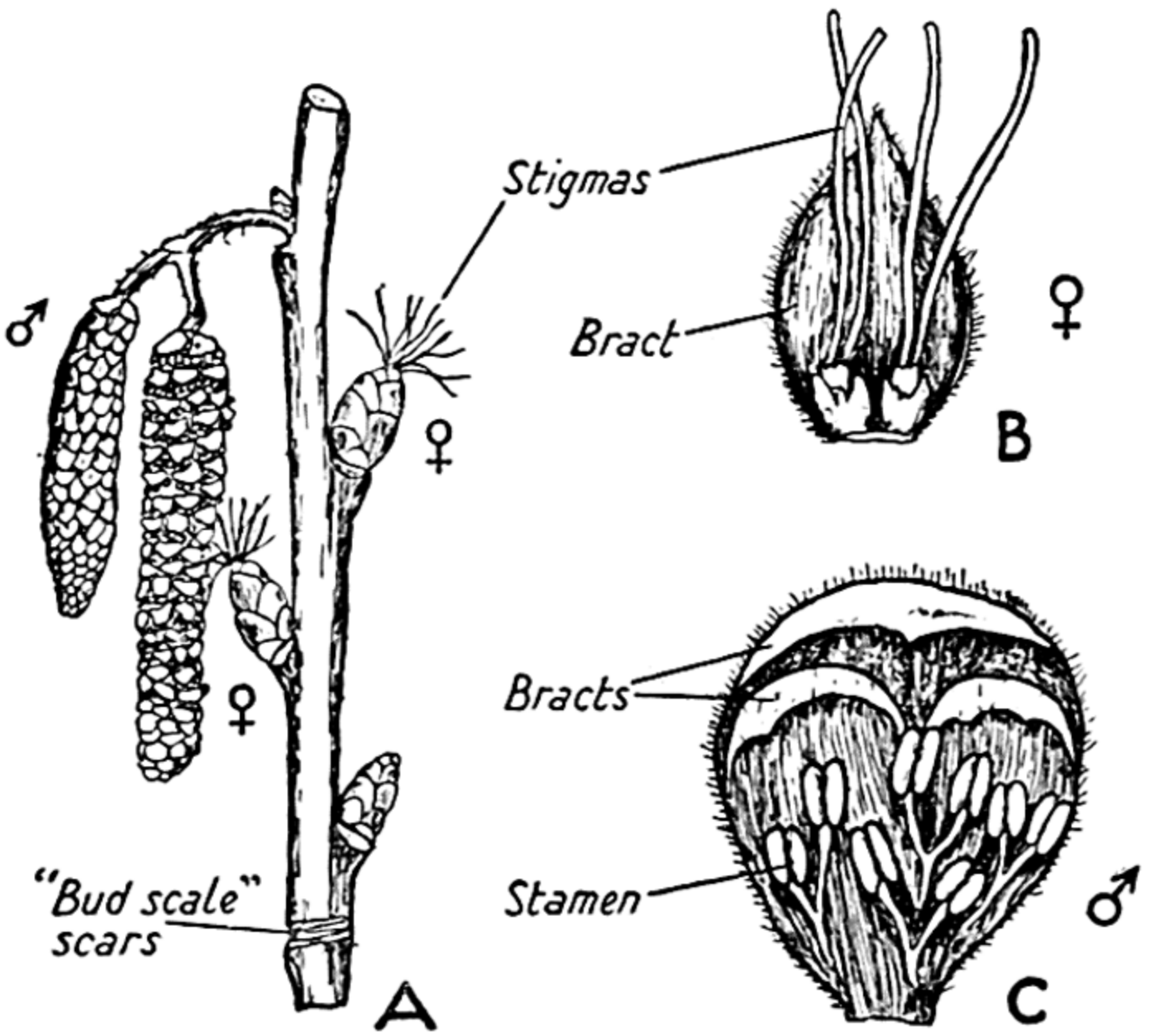


Fig. 148. Inflorescence and Flowers of Hazel. A. Shoot bearing inflorescences, one catkin still unopened (×1). **B.** Two female flowers (×10). **C.** A male flower (×10)

The female inflorescence looks like an ordinary vegetative bud, but may be distinguished by its crimson, projecting stigmas. Each bud is covered with brown scale leaves and contains about ten pistillate flowers. The flower consists of a gynaecium with two stigmas, surrounded by a very simple double perianth (cp. Fig. 148 B).

The pollination of hazel is effected by the wind. The exposed position both of the stamens and of the whole catkin, the fact that the catkin is loose and hanging, so that it is set swinging by every puff of wind—all these features facilitate the escape

of pollen, while the projecting stigmas readily catch some of it.

Exercises

Examine hazel bushes in winter, and sketch the young catkins.

Examine and draw a fully opened catkin, and investigate the structure of the little flowers of which it is formed.

Examine a hazel twig for female inflorescences. You can recognize them in March by the tuft of red stigmas which protrudes from them. Sketch one of these buds; also dissect it with mounted needles, and draw under a lens the structures of which it is composed.

Hazel has typical wind-pollinated flowers. Other flowers with this method of pollination should now be examined, e.g. poplar, oak, ash, birch; grass flowers, dock, dog's mercury, stinging-nettle, &c.

Exercise. Examine and sketch the parts of any of the above flowers which are available.

All wind-pollinated flowers have certain features in common. The method is obviously a wasteful one; a great deal of pollen must be lost for the one grain that hits its mark, i.e. lands on a stigma of its own kind of flower. How wasteful it is was made clear by an investigation carried out in the United States. In the spring of 1934 a botanist examined the deposit from a dust-storm, and found that some 34·7 tons of dust fell on every square mile of land, of which no less than 3·4 tons consisted of oak pollen. In England it is the abundant grass pollen of May and June which is the principal cause of hay-fever. Wind-pollination is indeed a wasteful process.

CHARACTERS OF WIND-POLLINATED FLOWERS. Wind-pollinated flowers usually agree in the following characters:

i. They form no nectar.
ii. They have no bright colour.
iii. They have no sweet scent.
iv. They form an abundance of light, dry, powdery pollen.
v. Their structure is such that this pollen is easily shaken out of the flowers by the wind. Sometimes the whole staminate inflorescence is loose and hanging, as in hazel and poplar; sometimes the individual anthers are

exposed, hanging loosely on their filaments, as in grass flowers.

vi. The stigmas protrude and are large and either feathery, as in grasses, or sticky, as in poplar.

vii. The flowers are either produced before the leaves are out, e.g. hazel, birch, poplar; or they are produced above the foliage, where they will catch the wind, e.g. grasses.

A little thought will make clear how helpful are all these features to wind-pollinated flowers. Such plants often grow in large communities. Much of the earth is covered by forest-land or grass-land. Grasses are wind-pollinated; so are many forest trees.

It is interesting to contrast the characters of wind- and insect-pollinated flowers. We find many marked differences between them, which are obviously related to their methods of pollination.

CHARACTERS OF INSECT-POLLINATED FLOWERS. Insect-pollinated flowers are more conspicuous than are those pollinated by the wind. They usually offer many attractions to their insect visitors, the chief of these being:

i. Nectar, which they produce in special nectaries; it represents food and drink to the insect.

ii. Pollen, which is another important source of insect food.

iii. Bright colour
iv. Sweet scent } which attract the insect's attention.

The pollen is not wasted as much in these flowers as in those which depend on the wind. Other features often exhibited by insect-pollinated flowers are:

v. The stamens are relatively few in number, and often hidden.

vi. The pollen is usually rough and adherent (cp. p. 445), not light and dusty as in wind-pollinated flowers.

vii. The stigmas are not exposed, and are not as large as in wind-pollinated flowers; indeed, both stamens and stigmas are often completely hidden.

The whole flower is a more highly specialized structure than the one pollinated by wind. This specialization increases as

we pass from simple, open flowers like buttercups, in which all the parts are exposed and easily reached, to such forms as a sweet pea, dead-nettle, or snapdragon. These flowers are far from simple. They are not open, but completely closed, and their essential organs are well hidden and almost inaccessible to most insects (cp. Fig. 150). Unlike the simpler radially constructed flowers (*actinomorphic*), they are only divisible by one plane into two similar halves (*zygomorphic*). This makes the nectar inaccessible to any insect that does not approach the flower in one particular way. When it does this, stamens and stigma are so placed that the insect inevitably comes into contact with them. In this way cross-pollination is effected.

In many such flowers there is a high degree of specialization to the visit of one kind of insect only, a form of adaptation which is not without danger to the plant, as the following examples make clear.

In one experiment, carried out by Charles Darwin, he found that

'twenty heads of Dutch clover or White clover (*Trifolium repens*) yielded 2,290 seeds, but 20 other heads protected from bees produced not one. . . . Humble-bees alone visit this clover, as other bees cannot reach the nectar.'

Another similar species of clover, the red clover (T. pratense), was early introduced into New Zealand as a crop plant. In view of Darwin's experiment, quoted above, we are not surprised to learn that at first, although they obtained abundant flower, the colonists got no clover seed. Eventually humble-bees were also introduced, and then they obtained seed in plenty.

Interesting maps can be plotted showing how the geographical distribution of an insect and a plant may be related. Often the one is dependent on the other; monkshood, for example, is only found in the region of humble-bees, and we know that this plant is pollinated solely by those insects. The mutual interdependence of flower and insect is a fascinating subject, which should be studied both in the field and from books which deal with these matters in greater detail. Certain specialized pollination mechanisms are described in the next chapter.

WIND POLLINATION VERSUS INSECT POLLINATION. Perhaps you will ask, 'Which of these methods of pollination is the better?'

'We cannot say that one of these methods is better than the other. The number of *species* that are insect-pollinated (entomophilous) is the greater, but probably not the number of *individuals*. The most successful dicotyledonous family, the Compositae [daisy family; cp. Figs. 151 and 152] is insect-pollinated; the most successful monocotyledonous family, the Gramineae (grasses), is wind-pollinated (anemophilous).

'Yet the influence which has directed the course of evolution towards the production of gay, fragrant blossom has been the relation of insect to pollination.' (Skene, *Biology of Flowering Plants*.)

FLOWERS AND INSECTS. When we study the relations between flowers and insects we find that both are benefited by this interdependence. The *insect* gains food, and often shelter, either for itself or for its eggs and larvae (grubs, maggots, caterpillars, &c.). We have all found these creatures in raspberry fruits, pea seeds, &c. The *flower* is cross-pollinated, with all the opportunities for better seed, &c., and, above all, for variation, which cross-pollination brings.

'If several varieties of cabbage, radish, &c., are allowed to seed near each other, a large majority of the seedlings thus raised turn out, as I have found, mongrels. For instance, I raised 233 seedling cabbages from some plants of different varieties growing near each other, and of these only 78 were true to their kind.' (Darwin, *Origin of Species*.)

Darwin investigated the effectiveness of the insect for this work of pollination. Let us quote just one case:

'Some holly trees bear only female flowers . . . others bear only male flowers. . . . Having found a female tree exactly 60 yards from a male tree, I put the stigmas of 20 flowers . . . under the microscope, and on all there were pollen grains. . . .

'As the wind had set for several days from the female to the male tree, the pollen could not have been carried by the wind. . . . Every female flower had been effectively pollinated by bees.' (Darwin, *Origin of Species*.)

INSECTS AND THE FORMS, COLOURS, AND SCENTS OF FLOWERS. The insect does not, as a rule, sip nectar while on the wing. Most insects alight for this purpose, and the shape of the flower is often such that some one part of the corolla makes a convenient alighting platform. Indeed, the habits of insects and the shapes and colours of our flowers are inextricably interwoven.

There even seems to be a certain relationship between the colours and scents of flowers, and the insects which visit them. 'Fly flowers' are often dull of colour and unpleasant in scent, bees seem to be specially attracted to blue flowers (cp. p. 241), butterflies by those which are red or white in colour. 'Moth-flowers' are often white or yellow, and many of them, e.g. evening primroses, tobacco plants, &c., emit a strong scent, and indeed only become fully open towards evening.

POLLINATION A SUBJECT FOR INDIVIDUAL INVESTIGATION. The whole subject of pollination can only be studied out of doors, and you should take every opportunity of observing these things for yourself. When you have watched any insect at its work, you should then examine both insect and flower, and try to discover what would be the probable effect of these activities on the essential organs—on the escaping pollen and on the receptive stigma.

This is a subject, as the quotations given from Darwin show, in which we can all be original investigators. Darwin was perhaps the greatest biologist who has ever lived, and yet you see how simple many of his methods were. One of the attractions of biology is that we need not rely entirely on books for our knowledge, but partly, at least, on our own independent observation. More than this, we can fairly easily, especially in the realm of natural history, add to the stock of common knowledge, and experience the joy of real discovery by finding out some as yet unknown fact for ourselves. Many great men, from Aristotle to Lord Grey of Falloden, have succumbed to the fascination of this study.

It is useful, in all such investigations, to be able to recognize at least the *insect group* to which the visitor you are watching belongs.

THE CHIEF INSECTS WHICH VISIT FLOWERS ARE:

i. Beetles (Coleoptera). These can be distinguished by their two front wings, which form hard, protective cases over the two back wings, which are used for flying.

ii. Flies (Diptera). These have one pair of wings only, which are thin, transparent, and with very few veins.

iii. Bees and Wasps (Hymenoptera). These have two pairs of membraneous wings. In some well-known forms the body is striped black and yellow.

iv. Butterflies and Moths (Lepidoptera). These have two pairs of large wings, covered with coloured scales, and a pair of long antennae. The butterfly's antennae are usually club-shaped at the end. Those of a moth are long, tapering, and feathery.

THE LENGTH OF THE INSECT'S TONGUE AND THE SHAPE OF THE FLOWER. With the exception of beetles, insects belonging to any of the above groups have hollow tubular *probosces* ('tongues'), by which they suck up liquid food, such as nectar. Flies have the shortest tongues, 3 mm. or less in length, while at the other end of the series the proboscis even of a British moth may be 30 mm. long when uncoiled, and in foreign moths it is often much longer. Hence, by looking at the structure of a flower, and especially at the position of the nectar, we can often make an accurate guess as to the type of insect likely to visit it. Some flowers are obviously only suited to short-tongued insects; such are all the 'umbel' flowers (Umbelliferae), the stonecrops and saxifrages, &c. At the other end of the scale are the flowers with long, narrow tubes, like honeysuckle, white convolvulus, and evening primrose, which are all pollinated by moths.

QUESTIONS ON CHAPTER XXXIII

For questions on this chapter see questions to Chapter XXXIV.

CHAPTER XXXIV

A STUDY OF CERTAIN SPECIAL POLLINATION MECHANISMS

TYPE I. THE SWEET PEA

HABITAT AND STRUCTURE. This is a well-known garden plant, growing to a height of about 8 feet. It climbs by tendrils which represent modified leaflets (cp. Fig. 122 B).

[1]The flower differs markedly in shape from those previously described. It is zygomorphic (cp. p. 457), which is characteristic of many flowers with highly developed pollination mechanisms. Its floral formula is K(5) C5 A(9)+1 G^{1}.

Exercises

Obtain complete plants and study the stems and leaves. Sketch a leaf with its tendrils and observe the wings of assimilatory tissue which run down on opposite sides of the stem. Notice how these wings are related to the leaves. These leaves have two leaflets and end in a group of tendrils. There are stipules at the leaf-base.

Examine a sweet-pea flower, take it apart, and make sketches which illustrate the structure of the whole flower and of its various organs. Notice carefully how wing and keel petals interlock at the base. Try to construct a floral diagram of the flower. Place your thumb and finger on the two wing petals, carefully press them downwards, and try to discover what would happen if a heavy insect alighted on them and depressed them in the same manner.

The sweet-pea flower has a calyx formed of five green sepals, which are joined below to form a cup. The corolla consists of five free petals, arranged as a large posterior standard, two lateral wings, and two anterior petals so joined that they form a trough-like keel.

Although quite free, the wing petals interlock with the keel at the base, so that wings and keel move together. In these flowers the wing petals form the alighting platform for the visiting insect.

The androecium consists of ten stamens, nine being joined by their filaments to form a thin cylindrical trough round the ovary. This trough is open along its upper (posterior) edge, where the one free stamen is placed.

[1] Before reading this chapter on flower structure the student is advised to read the summary given on pp. 473 and 474.

Sepals, petals, and stamens are inserted on the rim of a slightly hollow receptacle. The flower is *perigynous* (cp. Fig. 153 B1).

The superior gynaecium is formed from a single carpel. The style is curved upwards and projects beyond the stamen trough. The ovary is surrounded by this trough, and nectar, produced by glands at the base of the stamens, collects in it. It can be obtained by an insect through the narrow slit along the top of the trough, where there is the single free stamen. The top of the style is thickened and hairy.

POLLINATION MECHANISM. Such is the structure of this flower. Nectar and pollen are both well hidden; it requires a 'clever' insect to find them. How different from the 'well-spread table' which a buttercup exposes to tempt any insect hovering above it!

These pea flowers (and there are many showing a similar structure—gorse, broom, vetches, clovers, laburnum, lupin, &c.) are usually pollinated by bees and humble-bees, which are intelligent insects. The bee alights on the wing petals; these are dragged down by the weight, bringing the keel down with them. The stigma is uncovered and touches the under surface of the insect. At this moment cross-pollination is effected.

The stamens have dehisced early, shedding their pollen into the tip of the keel. As the weight of the insect depresses the keel still farther, the hairs on the style, acting like a sweep's brush, push out some of the pollen, which is thus deposited on the hairy body of the insect as it stands sipping nectar.

When it flies away to another flower much of this pollen will be lost, being brushed by the bee into his pollen-baskets and carried to the hive (cp. p. 494); but enough is left to effect cross-pollination.

When the bee leaves, the parts of the flower return to their original position, the keel once more hiding from view both stamens and gynaecium.

THE POLLINATION MECHANISM. A SUMMARY. We see that the pollination mechanism of this flower is a very specialized one. But we cannot study this mechanism at work in sweet peas, for these highly cultivated flowers are always self-pollinated

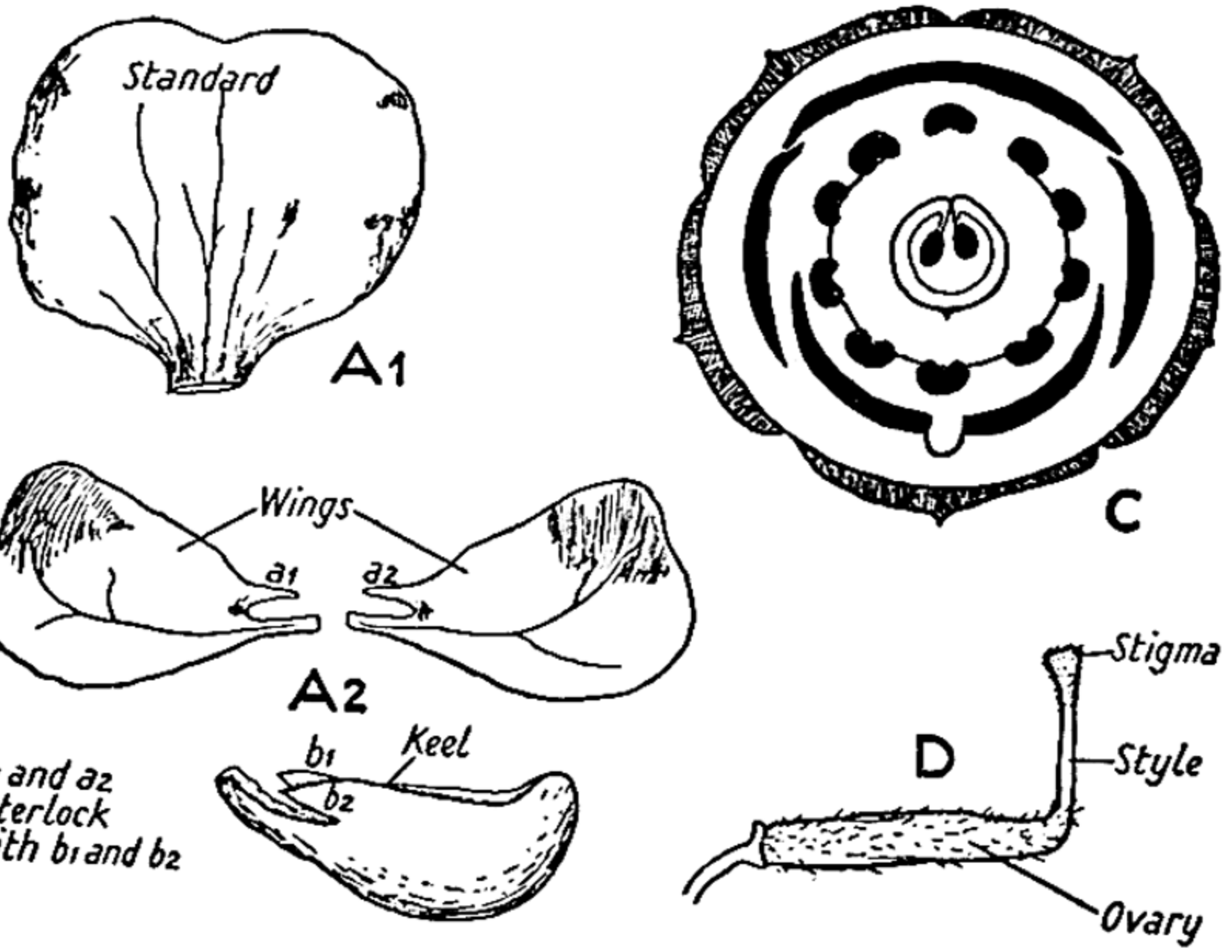


Fig. 149. Structure of Sweet-pea Flower. A1, A2. Corolla of petals. B. Flower after removal of petals (diagrammatic). C. Floral diagram. D. The gynaecium

in England, pollination occurring before the flower opens. So all the attractive mechanisms which they display are apparently useless. Unlike the clovers (cp. p. 457), most peas can, in the absence of insects, be self-pollinated. This fact has been of great use in the study of heredity. Many of MENDEL's experiments (cp. p. 436) were carried out on edible peas, which, like the sweet peas, are self-fertilized. Unless he cross-pollinated them artificially, he could be sure that no new factors would be introduced from a second parent to complicate the results of his experiments.

TYPE II. THE SNAPDRAGON

HABITAT AND STRUCTURE OF FLOWER. This is a perennial Mediterranean plant which grows in stony places, even on old walls. It is grown in England as a garden plant, having become almost wild in some districts. Its closed, zygomorphic flower is very familiar; it is rather like that of the toadflax, and should be compared with it.

Exercises

Examine a flower and make sketches of its parts. Notice particularly the relative position of stamens and stigma in (*a*) newly opened, (*b*) older flowers. Consider the flower from the point of view of an insect approaching it and seeking for a landing-place. Where would be the alighting platform?

Compare and contrast the gynaecium of the flower and the ripening and fully ripened fruit. Make diagrams illustrating the structure.

The flower of a snapdragon consists of calyx, corolla, androecium, and gynoecium. Its floral formula is K(5) C(5) A4 G($\frac{2}{2}$): the brackets denote that the members of the whorl are fused with each other, at least in part. It is very zygomorphic, the two-lipped corolla is tightly closed, and all the essential organs hidden.

The green hypogynous calyx (cp. Fig. 153) is formed of five joined sepals

The coloured hypogynous corolla consists of five joined petals, forming a long corolla tube. Two petals form the upper (posterior) lip, and three the lower (anterior) lip of this tube. The anterior lip forms the alighting platform for the visiting insect.

The androecium consists of four stamens, the two anterior being longer than the posterior pair (cp. Fig. 150 A). The stamens are

attached to the bottom of the corolla tube, and their position with regard to the petals is best seen in a very young bud. As the corolla lengthens the filaments of the stamens elongate and curve, so that the four anthers are brought into the posterior position, i.e. up to the back of the corolla tube.

The superior gynaecium consists of two joined carpels, with axile placentation (cp. p. 475). The stigma is forked (bifid).

The gynaecium ripens into a dry fruit (capsule) which opens by three pores to set free the numerous tiny seeds.

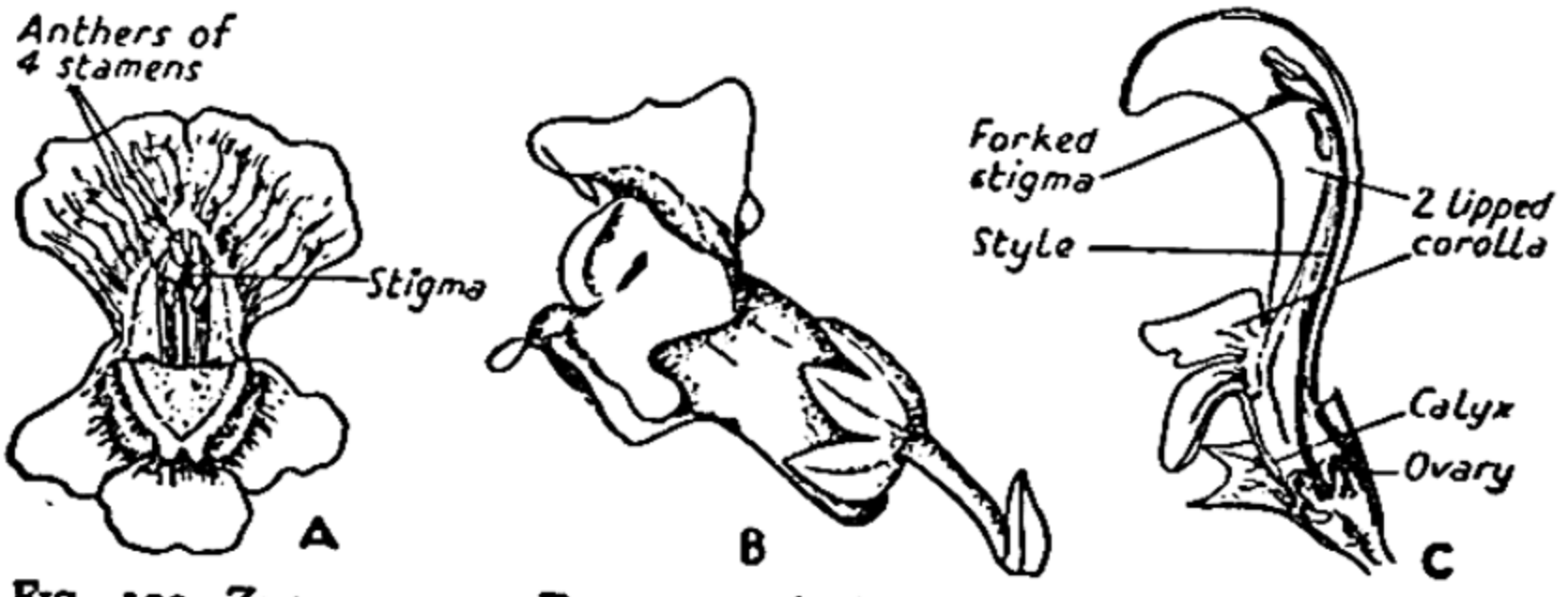


FIG. 150. ZYGOMORPHIC FLOWERS. **A, B.** Snapdragon. **C.** Dead-nettle, showing relative positions of stigmas and stamens at time of pollination

POLLINATION MECHANISM. The snapdragon is a typical bee flower, and is almost always pollinated by humble-bees, though smaller bees occasionally manage to effect an entrance. Nectar is secreted by a disk at the base of the ovary, and collects in the bottom of the corolla tube. The stamens lie under the upper lip of the corolla, with the stigma just above them. The heavy bee, alighting on the lower lip of the corolla, drags this down by its weight and forces open the entrance to the tube (cp. Fig. 150 A).

The insect pushes into the flower and touches the stigma. Then, probing still farther after nectar, it receives pollen from the stamens on its back. This is carried away and can be rubbed off on to the stigma of the next flower visited. So cross-pollination is effected.

A very similar mechanism can be seen in the *foxglove*, whose flower should be examined. Its structure closely resembles that of the snapdragon, except that the tube is wide open.

The foxglove is pollinated exclusively by humble-bees; they are the only insects large enough to fill the bell and so to deposit pollen on the stigma.

The stamens of this flower ripen before the stigma becomes receptive (protandrous), but there is some overlap, so that self-pollination is possible (cp. p. 445).

The *dead-nettle* is a very common zygomorphic flower with a somewhat similar structure and a similar pollination mechanism. It is pollinated by long-tongued bees (cp. Fig. 150 C).

TYPE III. THE COMPOSITAE

Daisies, dandelions, marigolds, sunflowers, cornflowers, thistles, &c.—many of our best-known flowers—are all essentially similar in structure. For this reason we group them together; they constitute the Composite family or Compositae.

This family is the most successful of all the flowering plants, and contains over 11,000 species. Flowers more or less resembling daisies and dandelions are found in all parts of the world. They are usually small herbs, and their excellent pollination mechanisms, the arrangements for the dispersal of their fruits by wind or animals, and the division of labour which often exists between the various small flowers or florets of the typical 'head'—all these advantages make us regard these plants as having reached a very high stage of development.

The family gets its name because the so-called 'flowers' are not flowers at all, but inflorescences. The true flowers (*florets*) are massed together on a flat floral axis, and the whole head (*capitulum*) is surrounded by one or more sets of leaves (the 'involucre of bracts') which does for the head what the calyx usually does for the individual flower, protecting it when in bud, &c.

The family falls naturally into three groups:

i. Those, like the dandelion, in which all the florets are long, strap-shaped structures (cp. Fig. 152).

ii. Those, like the cornflower,[1] thistles, and groundsel, in which they are all tubular structures.

[1] The outer florets of the cornflower have lost their stamens and carpels, and hence can function only as attractive organs.

iii. Those, like the sunflower, in which the outer ones are strap-shaped, the inner tubular (cp. Fig. 151).

Exercise. Examine the flowering heads of: (*a*) dandelions, hawkweeds, hawkbits, &c., (*b*) cornflowers, hardheads, groundsel, (*c*) sunflowers, daisies, ragwort, &c., and notice the nature of the individual florets.

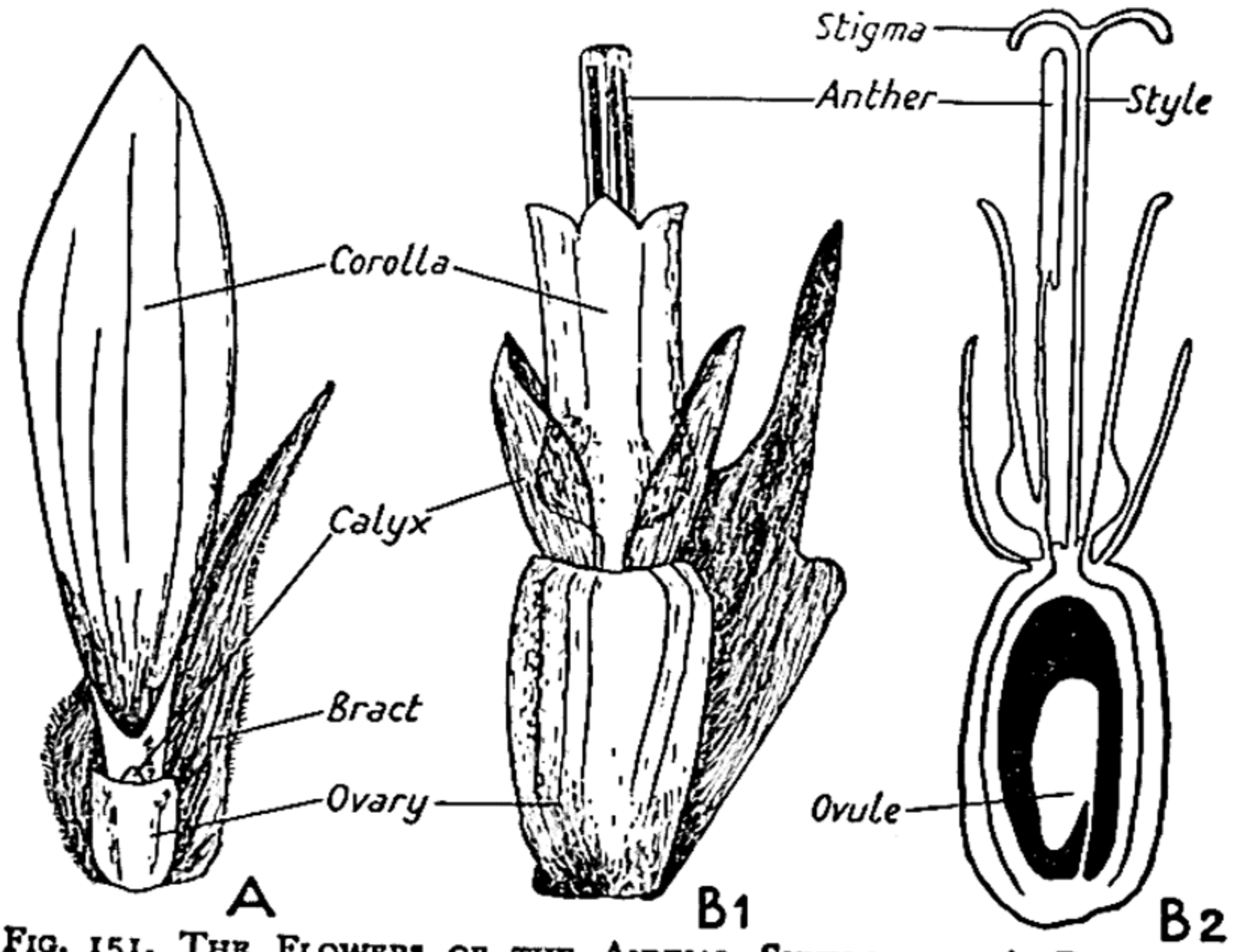


FIG. 151. THE FLOWERS OF THE ANNUAL SUNFLOWER. **A.** Ray floret. **B1, B2.** Disk florets. **B1.** Whole floret. **B2.** Longitudinal section of **B1**

THE ANNUAL SUNFLOWER. *Habitat and floral structure.* This is not a native British plant, but is often grown in gardens, where the very large flower-head forms a striking object. We have already studied its fruit and seed (cp. Fig. 106), its germination (cp. Fig. 108), and the structure of the young stem (cp. p. 94).

Exercise. Examine the capitulum of the annual (or perennial) sunflower. Make sketches which illustrate the structure of:

(*a*) the whole capitulum, (*b*) a single ray floret, (*c*) a disk floret.

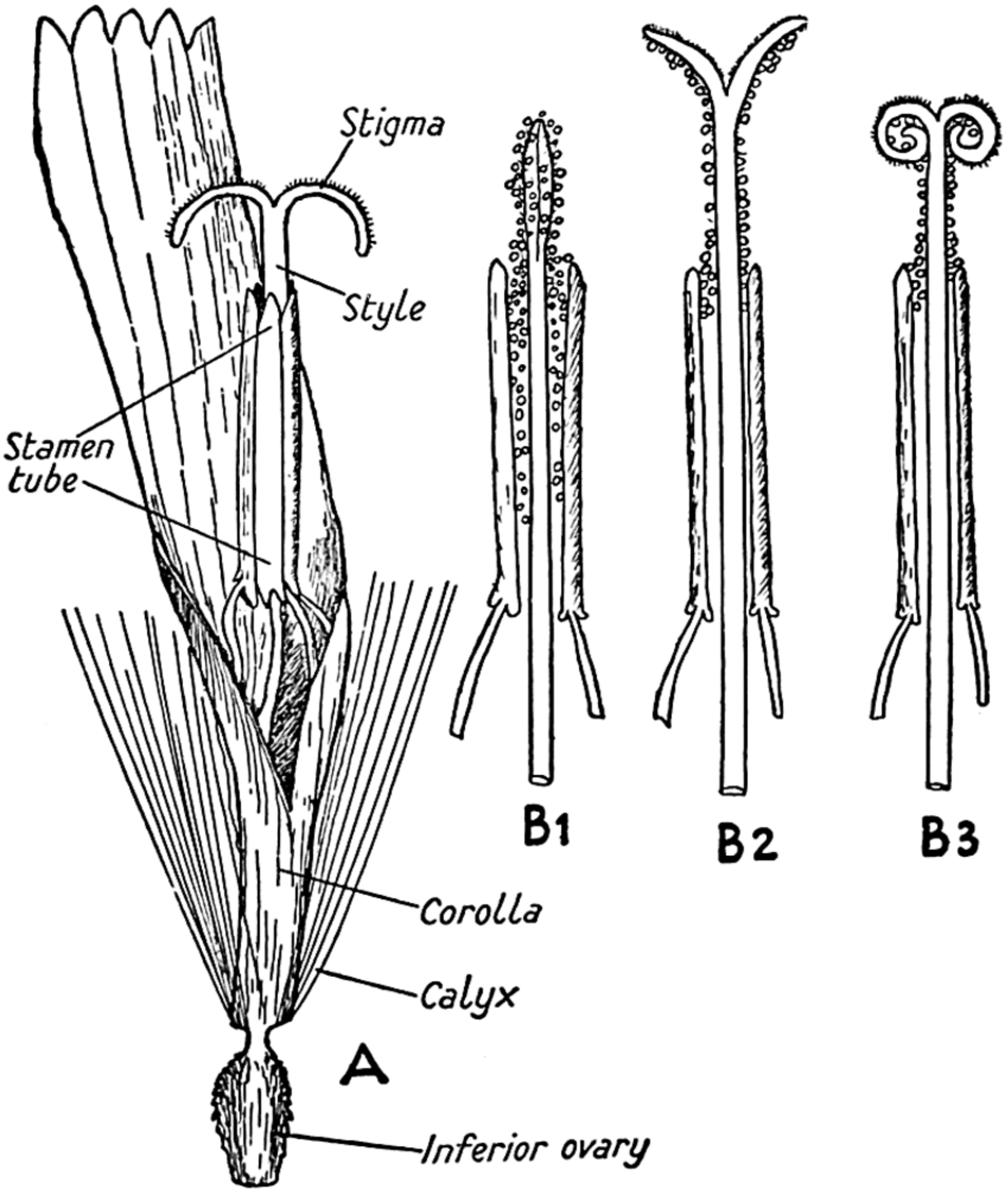


Fig. 152. Floret of Dandelion and its Pollination. A. Floret of dandelion (×3). **B1.** Pollen exposed (male stage). **B2.** Stigmas ready for pollination (female stage). **B3.** Self-pollination

In the sunflower the capitulum bears florets of two kinds, each arising in the axil of a white, membraneous bract.

The ray floret consists of a vestigial calyx, represented by one or two very small sepals; a zygomorphic corolla of five petals, joined to form a long yellow strap (cp. Fig. 151 A). The flower is incomplete, and quite sterile, having lost its reproductive function and serving merely to make the whole head more conspicuous (cp. p. 471). There are no stamens, and although there is an inferior ovary (cp. p. 473) it has neither stigma nor style, and forms no ovule.

The disk floret consists of a vestigial calyx of scale-like sepals, usually two; a regular tubular corolla of five joined petals, which is epigynous (cp. p. 473); an androecium of five stamens united by their anthers, their filaments being separate and attached to the base of the corolla tube; a gynaecium consisting of two joined carpels, which form an ovary containing only one ovule; this ovary is inferior (cp. p. 473); there is a long style and a bifid stigma.

THE POLLINATION MECHANISM OF THE COMPOSITAE.

Exercise. Examine a well-opened sunflower head, remove from it: (*a*) an unopened floret, (*b*) a recently opened floret, (*c*) a fading floret; sketch them carefully, and try to discover:

(i) how and when pollen is exposed, (ii) how and when the stigmas are exposed.

In sunflowers, and indeed in all the Compositae, the florets of any one capitulum do not open simultaneously. The whole head is conspicuous and attractive, and nectar is produced by each floret at the base of the style (cp. Fig. 151 B2). It rises in the corolla tube, and can be reached by quite short-tongued insects, such as flies and short-tongued bees, which crawl about over the top of the capitulum. There is, in these Composite flowers, no adaptation to any particular pollinating insect. In a young, newly opened floret the style is short, and lies within the stamen tube (cp. Fig. 152 B1). The stamens dehisce introrsely, and shed their pollen into this tube.

The hairy style now elongates and gradually sweeps the pollen out of the top of the anther tube (cp. Fig. 152 B1). It is thus exposed, and visiting insects will be powdered with it.

The growth of the style continues, and the two lobes of the stigma separate, exposing their inner receptive surfaces (cp. Fig. 151 B2). They are now ready to receive pollen.

The lobes of the stigma continue to separate, finally curling back until they touch with their upper surfaces some of the pollen which still adheres to the hairs on the style (cp. Fig. 152 B3). In this way self-pollination is assured in case cross-pollination does not take place. Nothing is left to chance in this most highly developed of families.

By this mechanism pollen is often transferred from one floret to another of the same head; but, as the insect flies from one head to another, cross-pollination also occurs. The pollination mechanism is very similar all through this large and successful family.

POLLINATION MECHANISM OF THE DANDELION. In every essential feature the structure of one of the constituent florets resembles that of the 'perfect' tubular sunflower floret just described (cp. Fig. 152 A). Each flowering head is open for about 8 hours on three consecutive days; it then closes while the typical fruit is being formed. These fruits are ready some 18 days after the flower first opened. When they are ripe the bracts separate again, exposing the fluffy 'parachutes' (cp. Fig. 155 A).

Examining any one head, we find that the florets open gradually from outside inwards, and they are all open by the end of the third day. On a wet or cold day, however, the head may remain closed, and its period of opening be prolonged in consequence.

In one of these florets, as in the sunflower, there is the same sequence of: i. newly opened floret, ii. exposed pollen (male stage, Fig. 152 B1), iii. exposed stigma with receptive surfaces separate (female stage, Fig. 152 B2), iv. the curving back of these in the last phase (cp. Fig. 152 B3).

Yet, in spite of all this, dandelion florets are never fertilized. They have acquired the power of producing fertile seeds from unfertilized ovules. The egg-cell grows *parthenogenetically*, i.e. without previous fertilization (cp. p. 494). This you can prove for yourself by the following simple experiment.

Experiment 107. With a sharp razor cut off the top of an unopened 'flower', removing the whole upper half of the capitulum. Tie over this head a cover of fine white gauze. The mutilation does not prevent seed and fruit formation. The characteristic fruit is formed unhindered. And, if sown, the seeds will germinate as well as those from an unmutilated head.

EVIDENCES OF EVOLUTION. The story of the dandelion with its perfect pollination mechanism, which is apparently never used, is an extraordinary one; but there is no end to Nature's curious ways. We often meet with similar instances of parthenogenesis in the insect world, e.g. among bees (cp. p. 494) and greenfly (cp. p. 506). How are we to account for it? The story becomes more intelligible if we believe in evolution, believe, that is, that living organisms were not created exactly as we see them to-day, but capable of infinite change and development. (Cp. p. 326.)

We then see in the dandelion a plant which, in spite of perfect sex organs, is losing its dependence on a sexual process, i.e. the latter is becoming *vestigial*. (We have abundant evidence that such things can happen (cp. p. 192).) One cannot help wondering what the ultimate effect of this will be, and whether the advantages will outweigh the disadvantages. Will the race of dandelions retain their vitality, or will they pay for this inbreeding by loss of vigour? Will variations be less frequent in the dandelions of the future? Many such questions occur to us, which the scientists of the future may be able to answer.

The occurrence of *vestigial organs*, such as the useless gynaecium seen in the ray florets of the sunflower, is also regarded as showing that evolution occurs. There are many cases of imperfect florets in these composite flowers. It seems that they have lost their original function, namely reproduction, and have become useful in quite a different way; they serve to make the whole capitulum attractive to insects. Many vestigial structures occur in both plants and animals; we shall return to a discussion of these matters on p. 515 et seq.

SELF-POLLINATION AND CROSS-POLLINATION. Although many plants are always self-pollinated, even, surprisingly enough,

some, such as sweet peas and garden peas, which possess definite structural features making cross-pollination more likely, yet on the whole it seems that cross-pollination gives better and more vigorous seeds. When we study methods of pollination we find many devices which definitely prevent self-pollination.

i. *If the sexes are separate*, i.e. if there are separate staminate and pistillate flowers which are borne upon different plants, cross-pollination is inevitable. This condition is found in such dioecious plants as willows, poplars, stinging-nettle, dog's mercury, holly, date-palm. The pollination of the female date-palms by the priests was a religious ceremony in ancient Babylon.

ii. *If the flowers are self-sterile*, i.e. if the flower cannot be fertilized by its own pollen, cross-fertilization is also inevitable. This condition is found in many cultivated fruit trees, in the purple and white clovers (cp. p. 457), in foxgloves, mignonette, &c.

iii. *If the flowers are dichogamous*, i.e. if their anthers and stigmas come to maturity at different times which do not overlap, self-pollination is impossible. If the stamens ripen and shed their pollen before the stigmas are receptive, the flower is called *protandrous*. Foxgloves, delphiniums, most Composites (cp. Fig. 152), campanulas, are examples of this, the more usual condition. If, on the other hand, the stigma is receptive before the stamens dehisce, the flower is *protogynous*, e.g. strawberry, hawthorn, apple, figwort, plantain, &c.

iv. *Sometimes there is some mechanical barrier* which prevents self-pollination; the stigmas and stamens are mature at about the same time, but so placed that the pollen cannot reach the stigmas, e.g. irises, violets, pansies. In primroses and cowslips, as is well known, there are two types of flower, 'pin-eyed' flowers, with the stigma above the stamens, and 'thrum-eyed', with the relative positions of these two parts reversed. The two forms of flower are borne on different plants and the device undoubtedly favours cross-pollination.

Experiments have shown that pollination of a 'pin-eyed' flower by 'thrum-eyed' pollen, and vice versa, gives the best results in number and vigour of seeds.

Exercise. Examine and sketch the flowers mentioned in the preceding paragraph, and investigate the pollination mechanisms.

DEVICES FOR SELF-POLLINATION. Dependence on wind or insects for so absolutely vital a process as pollination is obviously a weakness in the way of life of the flowering plant. Hence it is not surprising to find that many have a second method of reproduction by vegetative means (cp. pp. 368–75 and 421). Further, many short-lived ephemerals are habitually self-pollinated, e.g. chickweed, groundsel. In other cases, as in the Composites, the pollination mechanism is such that self-pollination occurs if cross-pollination fails. Finally, some plants form two different kinds of flower, special inconspicuous, self-pollinated flowers being produced after the better-known insect-pollinated ones are over. Look for these small, bud-like *cleistogamous* flowers in summer on plants of violet, wood-sorrel, &c.

A SUMMARY OF THE CHIEF FEATURES OF FLORAL STRUCTURE

Flowers differ greatly in structure. The chief features to be noticed in comparing them are:

(1) The number of whorls of floral leaves and the number and arrangement of the members of each whorl.

(2) Are the perianth leaves (i.e. the sepals and petals) free, that is inserted separately on the receptacle, or joined in some way to each other? If so, how?

(3) Do the perianth leaves arise from the receptacle

(*a*) below the ovary (hypogynous flowers)? (Cp. Fig. 153 A.)

(*b*) above the ovary (epigynous flowers)? In such flowers the receptacle is hollow, it encloses and is joined to the ovary (cp. Fig. 153 C).

(*c*) round the ovary (perigynous flowers)? The receptacle in these types is shaped like a shallow saucer or even like a cup, and the sepals and petals arise from its rim (cp. Fig. 153 B1, B2).

(4) Is the flower actinomorphic or zygomorphic, i.e. can it be divided by at least three or by only one plane into looking-glass halves?

(5) Is the gynaecium formed of one carpel or of more than one? If the latter, are these carpels all free (apocarpous), or are they joined to each other (syncarpous)?

In syncarpous ovaries the method of joining of the carpels affects the position of the ovules within the ovary, i.e. it affects their placentation. Sometimes they are so joined as to form an ovary with

several compartments or loculi, the number usually corresponding to the number of carpels. Such placentation is axile; the ovules are found in the centre of the ovary (cp. Figs. 154 B, 156 B1).

Sometimes the carpels are joined edge to edge so that there is only one chamber in the ovary (unilocular). Such placentation is called parietal. There are several rows of ovules on the ovary wall, the number of rows usually corresponding to the number of joined carpels (cp. Figs. 154 A, 156 A1).

Finally, if in an ovary with axile placentation we imagine that the partitions between the chambers break down, the placentation becomes free-central. The ovules remain on an upstanding column (representing the free placentas) in the middle of the ovary (cp. Fig. 154 C).

Exercise. Examine flowers of different structure to illustrate the above facts; for example:

bluebells (hypogynous; syncarpous ovary with axile placentation);
rose (perigynous; ovary apocarpous);
apple or pear (epigynous; syncarpous ovary; axile placentation);
primrose (hypogynous; sympetalous; syncarpous ovary; free central placentation);
violet or pansy (hypogynous; zygomorphic corolla; syncarpous ovary; parietal placentation).

QUESTIONS ON CHAPTERS XXXII–XXXIV

1. Describe with the aid of labelled diagrams the structure of any named flower. What do you know of:
(*a*) its pollination mechanism,
(*b*) the events which lead to the formation of the fruit?

2. By means of fully labelled diagrams compare the structure of the two flowers provided and explain the method of pollination in each of them. (L.G.S.)

3. Describe a buttercup flower, and say what you know of the functions of its various parts. How would you distinguish between the three commonest species of buttercup?

4. Compare the whole plant of a land buttercup (name the species) with a plant of water-crowfoot, and point out how far the differences between them are related to differences in habitat. (C.L.)

5. Describe, with the aid of labelled diagrams, one wind- and one insect-pollinated flower, and point out the chief differences between the two forms you describe. (C.L.)

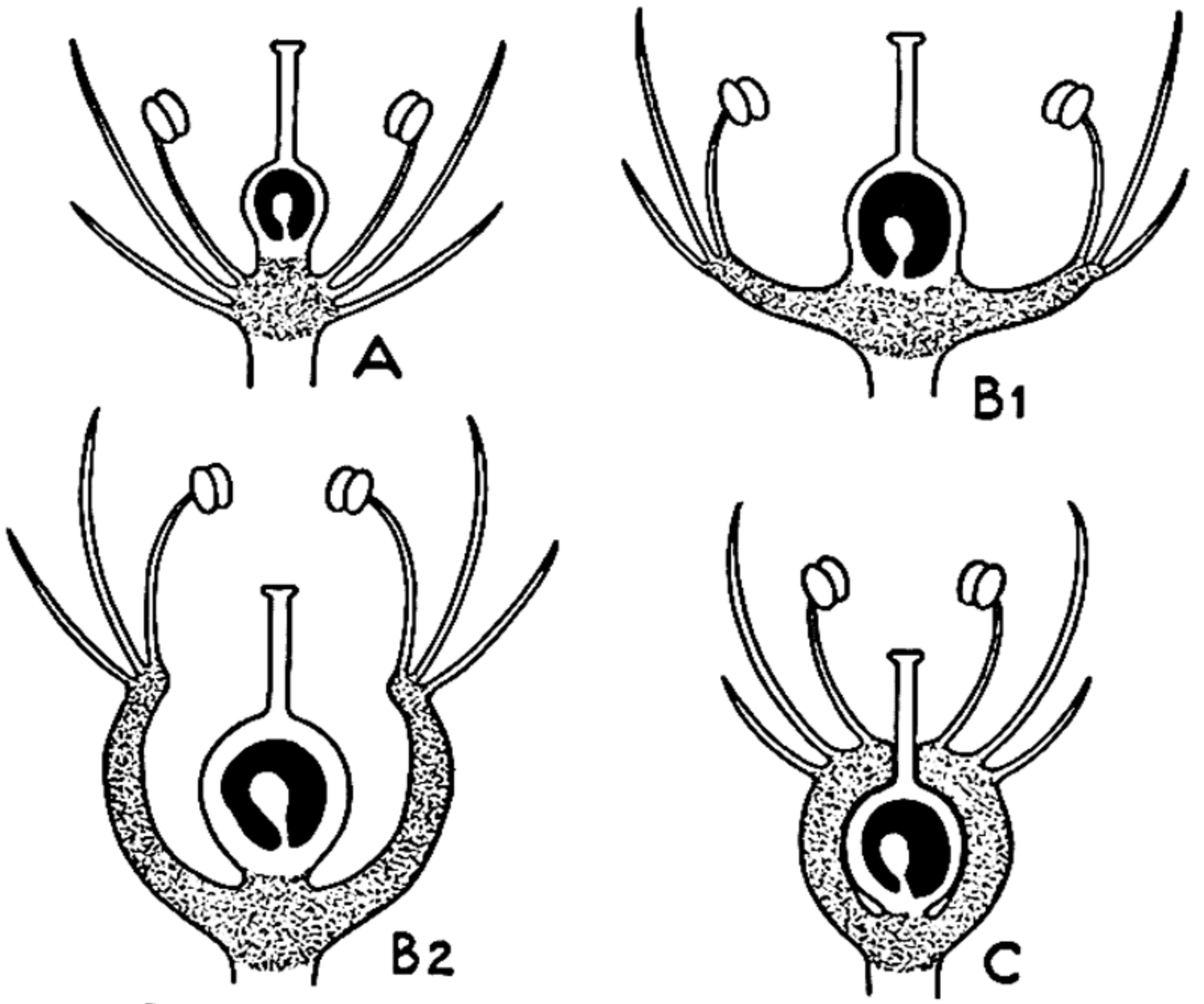


FIG. 153. THE DIFFERENT FORMS OF THE RECEPTACLE. **A.** Sepals, petals, and stamens hypogynous; ovary superior. **B1, B2.** Sepals, petals, and stamens perigynous; ovary superior. **C.** Sepals, petals, and stamens epigynous; ovary inferior

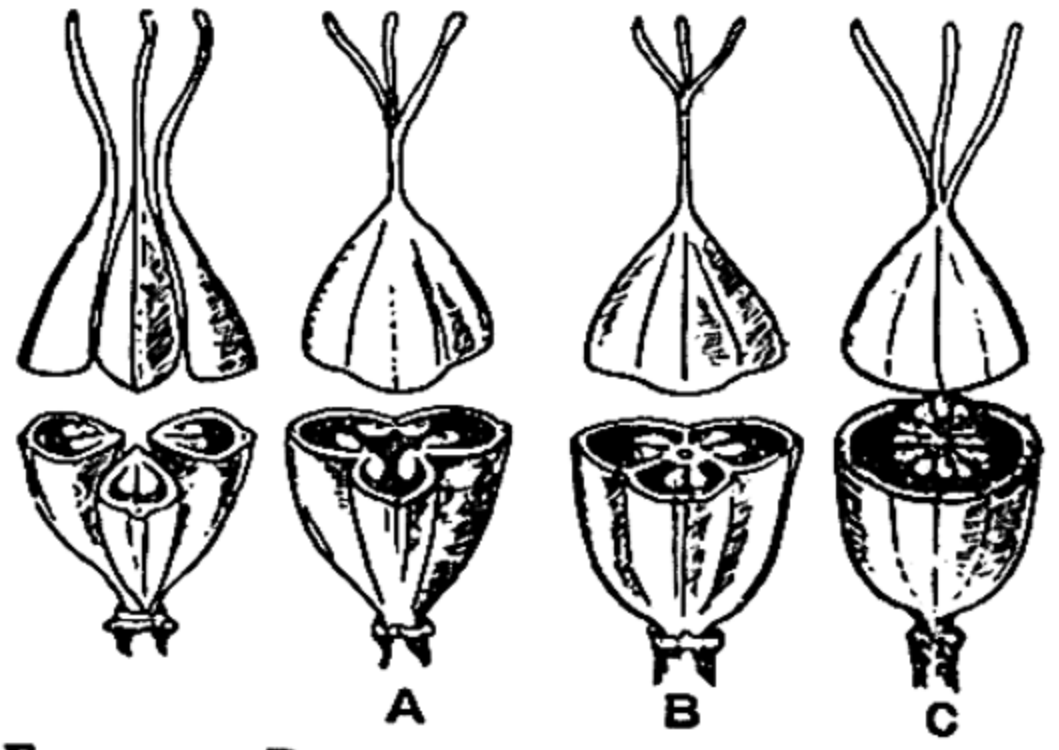


FIG. 154. DIFFERENT SYNCARPOUS OVARIES FORMED FROM THREE CARPELS. **A,** Parietal; **B,** Axile; **C,** Free-central placentation

6. Write a short essay on the part played by insects in the pollination of flowers. (L.G.S.)

7. Describe and give diagrams illustrating the structure of the flower and fruit of either rose, bluebell, sweet pea, snapdragon, or sunflower, and give an accurate account of the method of pollination, naming and describing the pollinating insect.

8. In a study of pollination it often appears that a flower is especially constructed for the visit of a certain type of insect. Select one named flower and insect, and describe in detail their relationship. (L.G.S.)

9. Give an illustrated account of the external features of the honey-bee, and show how this insect brings about pollination in the sunflower. (O.L.)

10. Describe the structure of a flower that is pollinated by a butterfly (or a moth). Explain the functions of the various parts of the flower; state also how pollination is effected, and in what way the insect itself benefits. (L.G.S.)

11. Give an account of any one flower whose pollination mechanism you have studied closely, showing clearly:

(*a*) which facts are based on your own personal observation,

(*b*) which you obtained from books, &c.

12. Describe the structure of one wind-pollinated and one insect-pollinated flower. How are they specially adapted to their methods of pollination? (C.L.)

13. Make diagrams to show the structure of any flower that is pollinated by long-tongued insects and describe exactly the behaviour of the insect in bringing about pollination. (L.G.S.)

14. What do you understand by:

(*a*) self-pollination,

(*b*) cross-pollination?

Describe *three* different ways in which cross-pollination may be brought about, naming the plants to which you refer. What are the advantages of cross-pollination? (C.W.B.)

15. What is meant by pollination? What is the difference between self- and cross-pollination? Explain how pollination differs from fertilization. Enumerate the general characters of insect-pollinated flowers. (Ox.L.)

16. Describe the fruit, seed, seedling, 'flower', and pollination mechanism in the sunflower.

17. Show by means of diagrams the structure of the flower of the buttercup (Ranunculus), and explain how pollination takes place in

this flower. What kinds of insect visit the buttercup, and for what purpose? (O.L.)

18. Give some account of the arrangements found among flowering plants for promoting cross-pollination, illustrating by reference to particular examples. (C.W.B.)

19. Make detailed drawings to completely illustrate the structure of the two plant specimens provided (gooseberry, clematis fruit). Name all the parts shown, and roughly identify the specimens indicating the means of dispersal in each case. (L.G.S.)

20. Make a floral diagram and sketches to illustrate the structure of a flower adapted for cross-pollination. Describe the method of pollination in the flower you select. (L.G.S.)

21. What do you understand by fertilization? Explain your answer with reference to a sweet pea, and any moss or liverwort which you have studied. (C.L.)

22. Describe, by means of diagrams only, the structure of the inflorescence and the flowers of the sunflower. Explain the statement 'the sunflower inflorescence is very highly specialized, showing considerable division of labour'. (Ox.L.)

23. Draw named diagrams to show clearly and in detail the structure of the flower of Pisum (pea). Indicate the utility of the arrangement of the parts for pollination purposes. (Ox.L.)

24. Name and describe (*a*) the flowers of any plant which shows cross-pollination ensured by the presence of separate male and female flowers, and (*b*) the flower of any plant which shows cross-pollination ensured by stamens and pistil ripening at different times while present in the same flower. (J.M.B.)

25. Name two plants the flowers of which are normally visited by insects. In each case describe in detail, with the aid of diagrams, what happens when these insect visits are made. Explain how you could prevent insects from visiting these flowers, and state what you would then expect to happen to them. (C.L.)

CHAPTER XXXV

FRUITS, THEIR STRUCTURE AND DISPERSAL

FRUITS AND THEIR CLASSIFICATION. A fruit is simply a case containing one or more seeds. This is generally formed from the ovary and ovules which ripen respectively into the fruit wall (pericarp) and seeds. In all epigynous flowers (cp. Fig. 153) the *receptacle* must also form a part of the *pericarp*, since from the beginning it was fused with the ovary wall.[1] Remarkable development of the receptacle is shown in some cases; e.g. in the strawberry, the rose hip, and the apple, in all of which it becomes more or less fleshy or juicy (cp. Fig. 156). The corolla and stamens often wither before fruit formation, but in some cases, usually in fruits formed from epigynous flowers, the calyx may persist, though often partially withered. The style and stigma may even form part of the fruit, as in poppy, geum, and clematis.

We may classify fruits into (*a*) *dehiscent* fruits, which open to set free the contained seeds (e.g. pods, capsules, &c.); (*b*) *indehiscent* fruits, which do not open and are usually one-seeded (e.g. nuts, achenes; (*c*) *splitting* fruits which separate into a number of one-seeded structures (e.g. the four nutlets of a dead-nettle fruit). Examples of all three types are usually present in any collection of the common fruits of the countryside.

Another classification divides them into (*a*) *dry* and (*b*) *juicy* (or *succulent*) fruits. This subdivision is very important when we are considering dispersal mechanisms.

Exercise. Make a collection of common fruits, examine their structure carefully, and make illustrative sketches. Try to ascertain from what type of ovary each fruit was formed, e.g. of how many carpels did it consist? Were these carpels separate (apocarpous) or joined together (syncarpous)? If joined, how? What was the placentation (axile, parietal, or free-central)? Was the ovary superior or inferior, &c.? (Cp. pp. 473–5.)

[1] The term 'false fruit' has sometimes unfortunately been applied to these and other forms; it is better to use it for fruit-like bodies which do not set seed, e.g. the banana of our shops.

FRUIT FORMATION.

Exercise. By comparing flowers and the fruits derived from them determine, for a few examples (e.g. buttercup, blackberry, geum, old man's beard, ash, plum, gooseberry, goosegrass, &c.), what changes occur in the ovary wall as the pistil ripens into a fruit. These changes affect its thickness, texture, colour, succulence, &c.

The pericarp of the mature fruit exhibits great variety of structure. It is dry and hard in nuts, achenes, pods, capsules, &c. (cp. Fig. 155). In many forms, on the other hand, it becomes succulent and often brightly coloured. In the fruits known as berries the whole pericarp becomes soft and succulent except for an outer skin (e.g. gooseberries, grapes, &c. (cp. Fig. 156 A1)); in another well-known type, the drupe or stone fruit, which is usually one-seeded, it becomes three-layered, developing as an outer skin, a juicy middle layer, and an inner 'stone' which encloses and protects the seed (e.g. plum, cherry, &c. (cp. Fig. 156 A2)). The fruit of blackberry, raspberry, &c., consists of a collection of little drupes or drupelets.

Exercise. Examine a collection of succulent fruits, pick out the berries and drupes, and sketch typical examples. In other juicy fruits the succulent part is usually the receptacle, or even the axis, as in the multiple fruit of the pineapple (cp. p. 484).

THE BIOLOGICAL SIGNIFICANCE OF THESE VARIATIONS IN FRUIT STRUCTURE. From the point of view of the plant the structure of the fruit matters not at all, so long as it affords adequate protection to the seeds and ensures their proper dispersal at the right time. This need for the dispersal of the seed is the important fact to be kept in mind in studying fruit structure. Seeds themselves are incapable of locomotion. But it is vitally important to the plant that they shall be carried far afield, not only far enough to remove them from competition with their parent, but also far enough to make possible the occasional colonization of new ground. This dispersal is effected in many different ways and usually by some external agent. There is always a very close connexion between the structure of the fruit and the means by which it is dispersed.

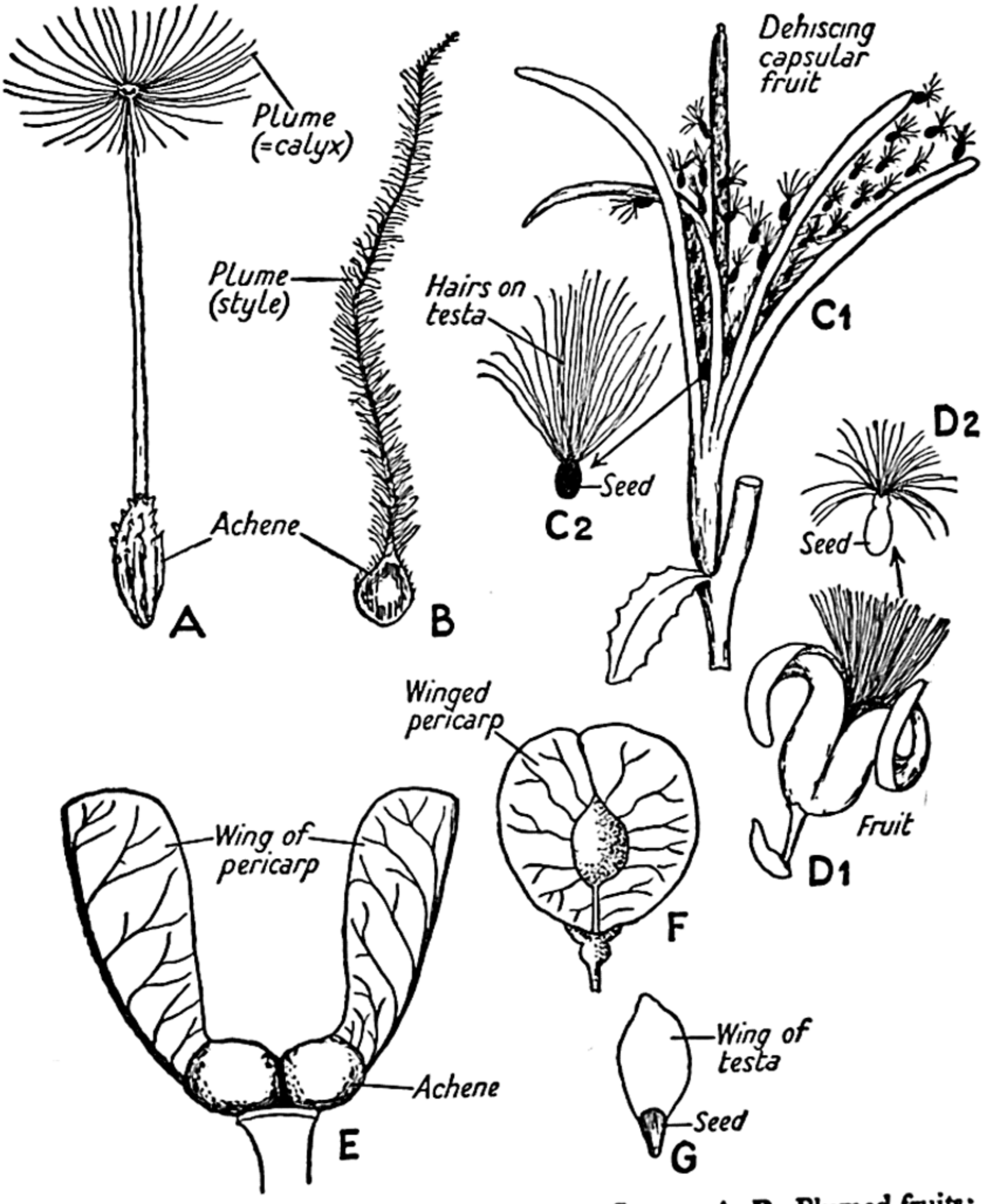


FIG. 155. WINGED AND PLUMED FRUITS AND SEEDS. **A, B.** Plumed fruits: **A,** dandelion; **B,** clematis. **C, D.** Plumed seeds: **C,** willow-herb; **D,** willow. **E, F.** Winged fruits: **E,** sycamore; **F,** elm. **G.** Winged seed: pine

DISPERSAL MECHANISMS

I. EXPLOSIVE MECHANISMS. Occasionally the dispersal of the seed depends on processes taking place in the fruit itself. A gorse pod explodes suddenly and flings out its seeds; this explosion is brought about by unequal drying of different parts of the pericarp. The capsules of 'touch-me-not' roll up when touched and fling out their seeds. In the Levant there is a plant known as the 'squirting cucumber', a name which sufficiently explains the mechanism by which it distributes its seeds.

II. DISPERSAL BY WIND. Most plants depend on the wind for seed dispersal. All small, light fruits and seeds will tend to be carried in this way, and during strong gales even larger fruits and seeds, e.g. acorns, horse-chestnuts, may be blown some distance. But many plants are not dependent on an occasional gale; their fruits or seeds have special structures, either a wing or a plume of hairs, which aid their dispersal by enlarging their surface so that they will keep afloat for a time even in the lightest breeze.

These organs for wind dispersal are formed from many parts of the plant; this is shown by the following table:

Organs for Wind Dispersal

Structure dispersed	*Origin of the dispersal mechanism*	*Example*
Plumed fruit	1. Plume formed from style 2. ,, ,, calyx	Clematis Dandelion, thistle, &c.
Plumed seed	Hairs formed on testa	Willow, willow-herb, cotton
Winged fruit	1. Wing an extension of the pericarp 2. Wing a bract	Elm, sycamore, ash Lime, hornbeam
Winged seed	Wing an extension of the testa	Pine, fir

Exercise. Examine the following fruits; compare if possible with the flowers. Sketch each fruit and determine the nature and mode

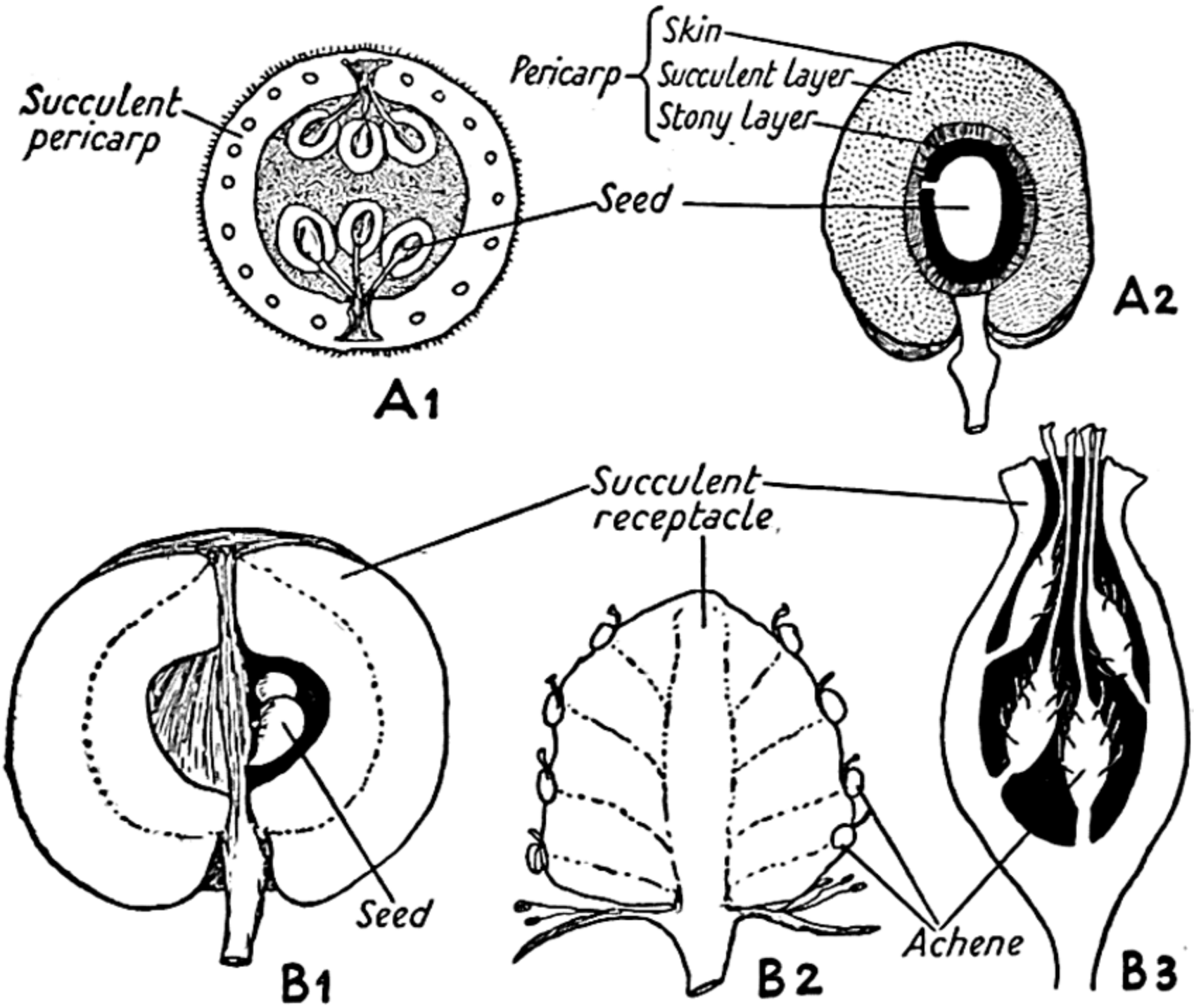


FIG. 156. SUCCULENT FRUITS. **A.** Pericarp succulent: **A1,** transverse section of a gooseberry; **A2,** longitudinal section of a plum. **B.** Succulent receptacle: **B1,** apple; **B2,** strawberry; **B3,** a rose hip—all in longitudinal section

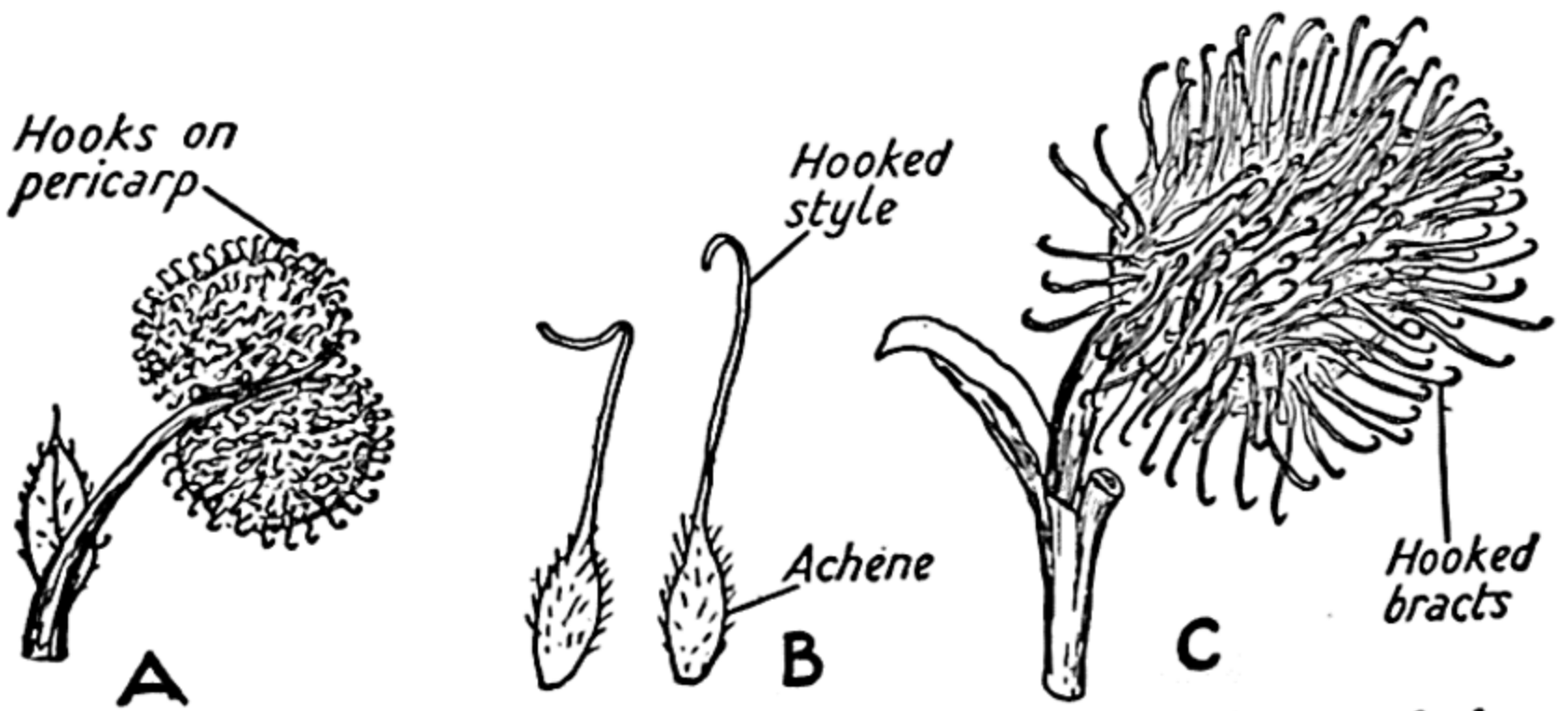


FIG. 157. HOOKED FRUITS. **A.** Goosegrass. **B.** Geum. **C.** Burdock

of origin of the organ for wind disposal: clematis (old man's beard), dandelion, thistle, willow, willow-herb, elm, sycamore, ash, lime, hornbeam, pine, fir, &c.

III. DISPERSAL BY ANIMALS. All fruits and seeds which offer food to animals will occasionally be dispersed by them. Rooks have been seen carrying acorns over a mile away from the nearest oak tree. Squirrels hoard acorns, beech nuts, &c., and often drop some and forget others. These examples make clear how such dispersal occurs.

Succulent fruits. Many plants have special structures which encourage this dispersal by animals. All succulent fruits are much sought after, birds, &c., eating the fleshy part and dropping or swallowing the seeds. If swallowed, these can often pass through the animal's alimentary canal unharmed, and still capable of germination.

Hooked fruits. Contrasted with this method of dispersal is the unconscious carrying about of fruits and seeds by animals, to whose wool, fur, skin, &c., they adhere. Darwin examined the soil sticking to the feet of an injured partridge, and allowed the seeds in it to germinate. In this way he obtained 82 seedlings. Many fruits develop hooks which, by attaching them to the animal's body, aid such dispersal. Such hooks may be formed from various parts of the plant (cp. Fig. 157).

Exercises

Examine a collection of succulent fruits and determine from what part of the plant the juicy pulp is formed, also how the seed is protected so that, even if swallowed, it is not digested.

Examine a collection of hooked fruits, e.g. hound's-tongue, carrot, goosegrass (cleavers), geum (avens), burr-marigold, burdock, teasel, agrimony. Try in each case to discover (*a*) the nature of the ovary from which the fruit was formed, (*b*) the part of the plant on which the hooks develop.

The pulp of fleshy fruits, like the hooks of burr fruits, may have very different origins. From the point of view of the plant it makes no difference whether the pulp (or hook) comes from ovary wall, from receptacle, &c.; the important thing is that it is formed and so is there to aid dispersal. The variety

of parts which can give rise to 'pulp' or hooks is illustrated by the following tables. The facts given there should be verified by examination of actual specimens.

Organs for Animal Dispersal

I. Succulent Fruits and Seeds

Structure dispersed	*Origin of dispersal mechanism*	*Examples*
Succulent berry	Juicy pericarp	Gooseberry, grape, mistletoe, tomato, &c.
„ drupe	Juicy middle layer of pericarp	Plum, cherry, &c.
„ pome	Juicy receptacle	Apple, pear, &c.
Various other fruits	Juicy receptacle	Hip, haw, strawberry, &c.
	Fleshy perianth	Mulberry
	Flask-shaped juicy inflorescence axis	Fig
Seed of dehiscent fruit	Oil bodies on testa	Gorse, castor-oil, violet, snowdrop

II. Hooked Fruits

Structure dispersed	*Origin of dispersal mechanism*	*Examples*
Hooked fruit (a burr)	Hooks formed on pericarp	Hound's-tongue, carrot, goosegrass
	Hook formed from sepals of reduced calyx	Burr-marigold
	Hooks formed on the receptacle	Agrimony
	Hook formed from style	Geum (avens)
Hooked capitulum	Bracts of capitulum are hooked	Teasel, burdock

IV. FLOATAGE BY WATER. The currents of rivers and oceans are important agents of dispersal; water plants, and those which live on river banks or on the sea shore, are often scattered in this way. Darwin found that many seeds will germinate after being immersed in sea-water for thirty days or more; such seeds, if accidentally blown out to sea, can survive for a time, and plants may occasionally be carried in this manner for many miles, even from a continent to an adjacent island. There is a small group of American plants on the west coast of Ireland whose seeds may have reached our shores in the Gulf Stream.

Many plants exhibit mechanisms for decreasing the average density of the seed so that the whole structure will remain afloat (Principle of Archimedes, cp. p. 314). The seeds of the water-lily hold bubbles of air in a special aril and drift in the current until the aril decays. They then sink to the bottom and become embedded in the mud, where they germinate. The fibrous husk of a coco-nut is full of air-chambers, the air being enough to float even this large seed. Coco-nut palms are a very characteristic feature of tropical islands.

DISPERSAL OF SEEDS. A SUMMARY. We have learned that seeds are dispersed in countless ways, and we know that plants come to occupy the most unlikely places, crevices in old walls, crannies in bare rock, &c., while even the driest desert 'blossoms' after a shower of rain. So effective are these various mechanisms that 'one year's seeding is seven years' weeding', in the gardener's adage, and by them the plant is largely compensated for its lack of powers of locomotion.

An opportunity was once given to naturalists to study the effect of these various dispersal mechanisms on a large scale, when the island of Krakatoa, near Java, was overwhelmed by the lava from successive volcanic eruptions during 1883. Every living thing was killed, and the island had to be gradually repopulated, the nearest land being twelve miles away.

By 1886 it was found that unicellular plants (algae and bacteria) had appeared and were preparing the way for higher forms. On the shore were the seeds, some germinating, of

certain strand plants, similar to those on the shores of the nearest land—Java and Sumatra. The island was gradually repeopled. By 1897 there were many flowering plants. Of these, over 60 per cent. had water-borne seeds, some 30 per cent. were wind-borne, and only 8 per cent. or less had seeds dispersed by animals. These observations made very clear the relative effectiveness of the various dispersal mechanisms under such conditions.

Struggle for existence. All living organisms have an enormous capacity for reproduction. One shepherd's-purse plant may produce 64,000 seeds, one female codfish lay 6,000,000 eggs a year. Now the size of the earth is strictly limited and it is obvious that only a very small proportion of these potential offspring can survive. Darwin found, for example, that, of 351 seedlings growing on a bare patch of earth 2 ft. by 3 ft. in area, 291 were soon destroyed, principally by insects.

Such facts led him to emphasize how fierce is the competition between one living organism and another. He called this competition *the struggle for existence*; we may study this in miniature on any piece of waste land. Soil is never left bare for long. Floods, earthquakes, droughts, and all manner of natural catastrophes may destroy life temporarily, but it comes creeping in again and is soon established as firmly as before. If you ever have the opportunity to study the colonization of an area left barren by the builder or roadmaker, &c., you should observe what happens carefully. You will find this an absorbing and interesting study.

> Kate has sown candy-tuft, lupins and peas,
> Carnations, forget-me-not and heart's ease;
> Jack has sown cherry-pie, marigold,
> Love-that-lies-bleeding and snap-dragons bold;
> But who knows
> What the wind sows?
>
> (T. Sturge Moore.)

QUESTIONS ON CHAPTER XXXV

1. Distinguish between a fruit and a seed and describe the mode of distribution in any *five* of the following. State in each case the nature of the parts by which the distribution takes place. Cherry, burdock, cleavers, apple, poplar, dandelion, willow-herb, sycamore. (L.G.S.)

2. Give an account of the part played by animals in the dispersal of fruits and seeds. Give detailed and fully labelled diagrams of the fruits and seeds you mention. (L.G.S.)

3. Explain carefully what you mean by a seed and a fruit. Describe the structure of the grain of maize (or wheat). (J.M.B.)

4. Describe three different methods of dispersal of seeds, and give drawings to illustrate *one* example of each method you describe. (J.M.B.)

5. Give an account of the principal means whereby fruits and seeds are dispersed. Name examples to illustrate your answer. (L.G.S.)

6. Give examples to indicate the association of animals with plants in the fertilization of the flowers and the dispersal of the seeds. (D.)

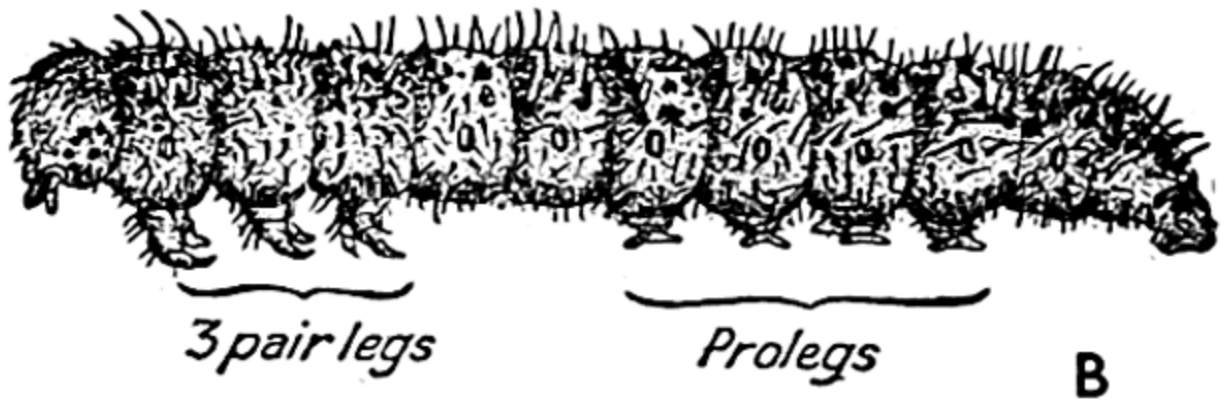
7. What is the difference between a fruit and a seed? In what ways are animals concerned in the distribution of fruits and seeds? Give examples. (L.G.S.)

8. Make detailed drawings to completely illustrate the structure of the two plant specimens provided. (Fruits of gooseberry and old man's beard.) Name all the parts shown and roughly identify the specimens, indicating the means of dispersal in each case. (L.G.S.)

9. In a few words state the essential difference between a fruit and a seed. Describe carefully and illustrate what you would see with the naked eye and a hand lens in any normal fruit (*a*) shortly after fertilization, (*b*) when fully opened. (Ox.L.)

10. Describe carefully fruits of any two types you have studied, and point out how the seeds within them reach the earth in nature. (Ox. & C.)

11. By what means are fruits and seeds disposed? Describe *four* examples of fruits and seeds in illustration of your answer. Of what advantage is it to plants that their seeds should be dispersed? (Ox.L.)



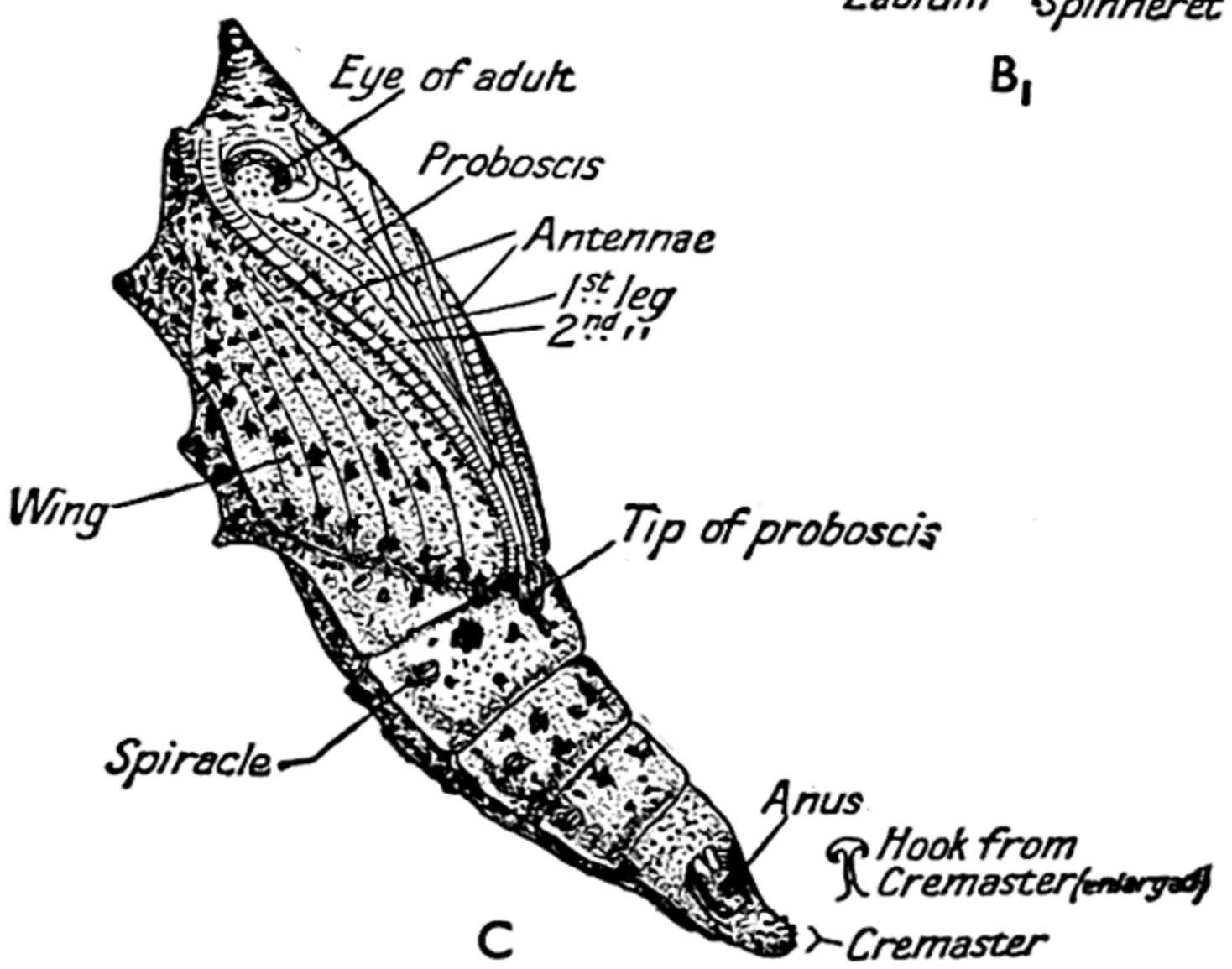
B



Egg (x 50)



B_1



C

Fig. 158. Stages in the life-history of the cabbage white butterfly—showing egg; B, larva (caterpillar); B_1, head of larva (more highly magnified); C, pupa

CHAPTER XXXVI

REPRODUCTION IN ANIMALS. INCREASING CARE OF THE YOUNG

THE great majority of animals reproduce sexually, and many, like the frog, immediately cast their eggs adrift, giving them little or no protection (cp. p. 319). Such creatures must produce innumerable eggs so that an occasional one may survive.

'The real importance of a large number of eggs or seeds is to make up for much destruction at some period of life; and this period in the great majority of cases is an early one. If an animal can, in any way, protect its own eggs or young, a small number may be produced, and yet the average stock be fully kept up; but if many eggs or young are destroyed, many must be produced, or the species will become extinct.' (*Origin of Species.*)

These words of Charles Darwin express a profound biological truth. Care of the young is always a sign of a high state of development. Let us examine some examples of this parental care among animals.

REPRODUCTION IN INSECTS

Exercise. Obtain some eggs of any common insect, e.g. silkworm, cabbage white butterfly, cockroach, &c., and study their development.

Many of these creatures can be kept quite easily in captivity. They may be placed in wooden boxes, preferably with sides of perforated zinc, or in large inverted bell jars over which muslin covers are tied. Fresh supplies of food, e.g. mulberry leaves, cabbage leaves, &c., must be given frequently.

Insects usually reproduce sexually. The males and females pair, the egg-cells are fertilized, and the eggs laid (cp. pp. 313 and 315).

I. CABBAGE WHITE BUTTERFLY. The eggs of the cabbage white butterfly are laid in May and again in late summer, usually on a plant of the cabbage family, i.e. on a plant which will serve the young caterpillar as food. Each egg is enclosed in a hard ridged shell, and contains a certain amount of reserve

food. Hence the protection and care given to the young organism are of varied nature:

(*a*) It is protected by its hard shell.

(*b*) It is provided with a little food to start it in life; the egg contains a certain amount of stored food (yolk).

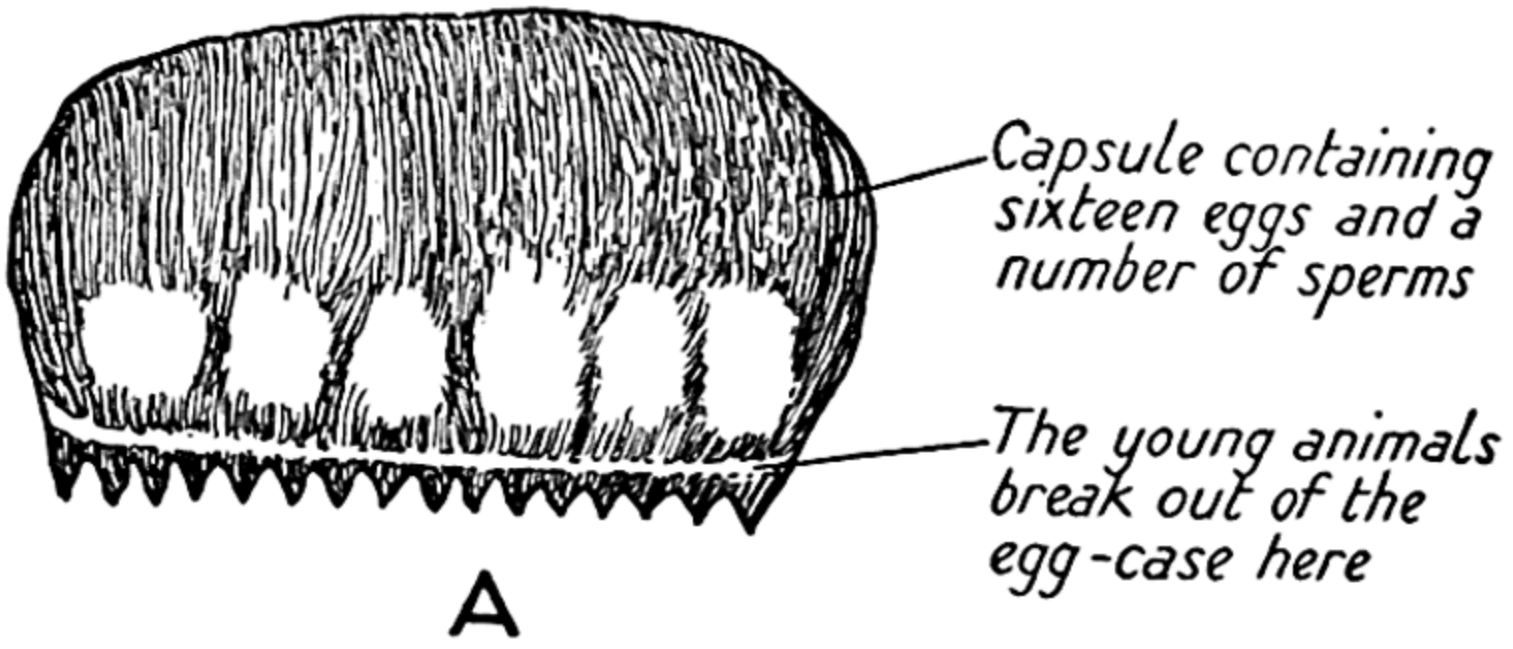


FIG. 159. EGG-CAPSULES. **A.** Reddish-brown egg-capsule of cockroach (×3). **B.** Brown, horny, egg-capsule of earthworm (×3)

(*c*) It is placed by its mother on the appropriate food plant, so that it need hardly move from the spot where it was 'born', but can complete its caterpillar life there.

In all these ways the mother butterfly looks after her offspring although, so far as we know, she never sees them. She flies away directly the eggs are laid.

II. THE COCKROACH. In the cockroach (cp. p. 156) sixteen fertilized egg-cells are enclosed in an egg-capsule, formed by a secretion from special glands. The female animal carries this capsule about for a time, eventually depositing it in some suitable dark crevice. Hence in these animals the egg is not immediately abandoned by the mother insect; she gives it some slight supervision.

III. THE ANT, A SOCIAL INSECT. Ants live in colonies which contain at least three kinds of mature insect—queens, workers, and males (cp. Fig. 160). The colony is formed by a queen. Among the yellow meadow-ants (Lasius flavus), for example, she escapes on some very fine day from her old home, accompanied by a swarm of males, is fertilized during this 'nuptial' flight, and then settles down quite alone to a life of egg-laying. Having bitten off her wings, she excavates a tiny burrow, retreats into it, and waits, untended and unfed, until a few of her eggs have developed into tiny wingless workers. It may take the queen some months to rear this first family. Eventually, however, the young workers are ready to leave the burrow, and to collect food for themselves and their 'mother'. Soon they begin to enlarge the burrow, excavating holes and passages in the ground, and gradually forming an ant-hill. In an observation nest the queen may often be seen, attended by many workers.

'They stroke her with their antennae and lick her, and attend upon her as she walks about in a leisurely manner, often dropping eggs as she goes. These are immediately picked up by the workers and transferred to one of the nurseries.' (Von Wyss, *Living Creatures*.)

Exercise. Construct a formicarium, consisting of two chambers, each having a glass floor and roof and wooden sides. The first or observation chamber is quite shallow, being only about $\frac{1}{8}$ inch deep. The second chamber is deeper, and a length of glass tubing connects the two. Such an apparatus is easily made at home.

Now look for an ant-heap, and remove enough soil to fill your boxes, which should have well-fitting but removable glass lids. Carefully search in the ant-heap and try to discover a queen. If you are successful, bring her home, with a few workers, pupae, larvae, and eggs. The easiest heap to raid in this manner is perhaps that of the yellow meadow-ant.

Fill your formicarium with the dry, sifted soil; bore a hole in the wood at one side of each compartment, through which you can moisten the soil with a fountain-pen filler. The holes are afterwards plugged with cotton-wool. Now introduce your captives into the deeper of the two chambers, and place a black cloth over the shallower one. Some of the ants will eventually discover this darkened part of the nest; having done so, they return to their companions and

apparently make their discovery known, for they all gradually migrate into it. Sometimes the queen goes with them willingly; sometimes a group of workers appear by their combined efforts to pull and push her into the new home. Eggs, larvae, and pupae are assembled by the workers, and the nursery is gradually organized. You can now watch the orderly life of the ant-heap. Give the captives food—either honey, a dead fly, or some banana skin, introducing this at one of the entrances provided for watering the soil.

All is now in order, and the ants will soon settle down. Keep them well supplied with food, keep the soil moist, but not wet, and cover the whole formicarium with a black cloth. If you uncover one part the ants will desert the part exposed to the light, and you can watch their antics.

Stages in the life-history of the ant. The eggs laid by the queen are looked after by the workers, who lick them over daily. From these, blind, legless, and helpless grubs (larvae) emerge, who depend on their 'nurses' for the satisfaction of their every need. They are kept clean (by licking), and are fed with a liquid which the nurses disgorge from their own crops. As the grubs grow, their attendants sort them out into different chambers of the nest, according to their size (cp. Fig. 160), the workers carrying them about much as a mother cat carries her kittens. Sometimes they are brought up near the surface, apparently for warmth; at others taken into the deeper recesses of the home, where there is less light and more moisture.

When full-grown the grub is covered with particles of earth by the worker, and spins about itself a silken cocoon. Within the cocoon it discards its skin, and a pupa resembling the adult animal is soon visible. Workers still look after it; when it is fully formed they open the cocoon, one making the slit (cp. Fig. 160) while another assists the young ant to escape. They help it to unfold its legs, at the same time supplying it with food. Gradually it becomes stronger, and can at last be left to look after itself. Its long period of dependence, not on its mother, but on the community to which it belongs, is ended.

A few days later the creature leaves the nest for the first time, and is ready to play its full part in the life of the ant-hill, whether it be as wingless worker, as winged male, or as a queen. From birth almost to maturity these animals are fed



FIG. 100. Interior of an ant-hill to show how the workers arrange the young according to the stage to which they have developed. In the top three chambers are very small larvae (grubs), in the fourth full-grown larvae, and in the bottom chamber cocoons, often erroneously called ants' eggs. (Reproduced from M. W. Wheeler, *Ants*, by permission of Columbia University Press)

and cared for. Care of the young has been brought to great perfection in the ant world.

IV. THE HONEY-BEE. Bees, like ants, often have a social life of great complexity. Honey-bees, for example, live in communities containing thousands of insects. These are of three kinds, queens, drones (males), and workers (sterile females),



FIG. 161. THE HONEY-BEE (× 1). On left, sterile female (worker); in centre, female (queen); on right, male (drone)

all of which are winged. Their food is more restricted than that of ants. The latter, though fond of sweet things, will eat animal and vegetable matter of many kinds, while bees' food consists entirely of pollen and nectar.

The queen is again the mother and founder of the whole hive. This home is started after the act of 'swarming', when the original queen leaves the old hive with her myriads of attendant workers. The swarm takes possession of a new site, and soon the younger workers are actively secreting and working the necessary wax, while older ones hollow it out into the well-known hexagonal cells. In each of these an egg is deposited by the queen, whose whole life is spent in egg-laying.

Stages in the life of the bee. The eggs[1] develop into larvae, which are fed at first on a liquid, consisting of partially digested food, which is prepared for them by the nurses, and at a later stage on a paste compounded of this liquid, honey, and pollen. The larva, becoming full-grown, is imprisoned in its cell, which contains a store of honey and pollen, by the attendant workers, who form a porous cup of wax, so closing the mouth of the

[1] Two types of egg are laid by the queen—*fertilized* egg-cells which develop into queens or workers, and *unfertilized* eggs which develop parthenogenetically (cp. p. 470) and always produce drones. Queens are produced by feeding the larvae from fertilized eggs with specially rich food.

cell. Shut up in this manner it spins an imperfect cocoon, within which, after two days, the pupa is clearly visible. About a week later this pupa casts its skin, and the young bee emerges. With the aid of its nurses it bites its way out of the cell, is cleaned and fed. In a few hours it is ready to take its full share in the work of the hive. At first, if a worker, it may clean the new nurseries; later it helps in the feeding of the young. Older still, it begins as a food-collector, at first gathering food from other bees as they come back from foraging expeditions (cp. p. 462) and storing it in special storage cells. Ultimately it goes out itself to collect nectar or pollen.

There are countless other tasks to be performed: more cells to build, to serve as nurseries, for food-storage, &c.; the hive to be kept clean and aired; all refuse, &c., removed; the colony protected from enemies, &c. Bees are not long-lived. In a few short weeks a worker dies, worn out by its ceaseless activity.

V. THE SPIDER. INSTINCT VERSUS INTELLIGENCE. When studying ants and bees it is tempting to regard their activities as signs of real intelligence, to think of them as caring for their young in the manner of human nursemaids and teachers. But, when dealing with the lower animals, and especially with invertebrates, we must beware of any such interpretation. This fact is well illustrated by the following stories, told by Fabre, a great French naturalist, of the Narbonne wolf-spider (Lycosa Narbonnensis). We have somewhat similar spiders (e.g. Lycosa soccata; L. picta of the sandy shore, &c.) in England, and the female animals of these species may often be seen dragging about a bag of eggs.

Fabre watched the formation of this bag by the female, and the laying of the eggs in it.

'A soft white pill results, and she carries this pill, slung to her stern, until the eggs are hatched. . . . It is a sight worth seeing, that of the Lycosa dragging her treasure after her, never leaving it, night or day, sleeping or waking, and defending it with a courage that strikes the beholder with awe.' (Fabre, *The Spider*.)

Fabre recounts many experiments with these spiders. He removed this 'living pill', and gave in exchange:

(*a*) A 'pill' taken from another spider of the same species.

(*b*) A 'pill' of different colour and texture from another species.

(*c*) A cork ball.

(*d*) A pellet of bright-red silk threads.

He shows that the spider seemed quite unable to distinguish between the 'pill' containing her own offspring and any of the foreign bodies which he offered her.

'Let us penetrate yet deeper into the wallet-bearer's stupidity.' [He threw her a cork ball in place of the 'pill', which he forcibly removed.] 'Lovingly she embraces the ball . . . fastens it to her spinnerets, and thenceforth drags it after her as though she were dragging her own bag.' [He gave her the 'choice' between her own pill and a cork ball, placing both within reach.] 'Will she be able to know the one that belongs to her? . . . The fool is incapable of doing so. . . . She makes a wild rush, and seizes haphazard at one time her own property, at another my sham product.' (Fabre, *The Spider.*)

Post-natal care. This spider is not intelligent, yet she is a most untiring mother. Not only does she drag her heavy pill about, but, after the hatching, she carries her young on her back, until gradually they drop off and begin life for themselves. Here again her care seems to be quite unintelligent. She does not trouble about her babies. If they fall off she makes no attempt to rescue them. She allows them to be replaced by the offspring of another spider without protest.

'To speak here of mother-love were, I think, extravagant. The Lycosa's affection for her offspring hardly surpasses that of the plant, which is unacquainted with any tender feeling and nevertheless bestows the nicest and most delicate care upon its seeds. The animal, in many cases, knows no other sense of motherhood. What cares the Lycosa for her brood? She accepts another's as readily as her own; she is satisfied so long as her back is burdened with a swarming crowd, whether it issue from her ovaries or elsewhere. There is no question here of real maternal affection.' (Fabre, *The Spider.*)

VI. THE EARTHWORM. This familiar creature, whose structure and way of life have already been described (cp. pp. 150–5, 211, 229, 291), is not remarkable for any exhibition of parental care, but because it is *hermaphrodite* (cp. p. 428). Like

Hydra and tapeworm (cp. p. 194), this animal possesses both male and female organs; their arrangement is shown, somewhat diagrammatically, in Fig. 162 A, which represents a portion of a worm, opened to display them.

The first stage in reproduction is the *mutual exchange* of sperms by two worms (cp. Fig. 162 B). These are passed into

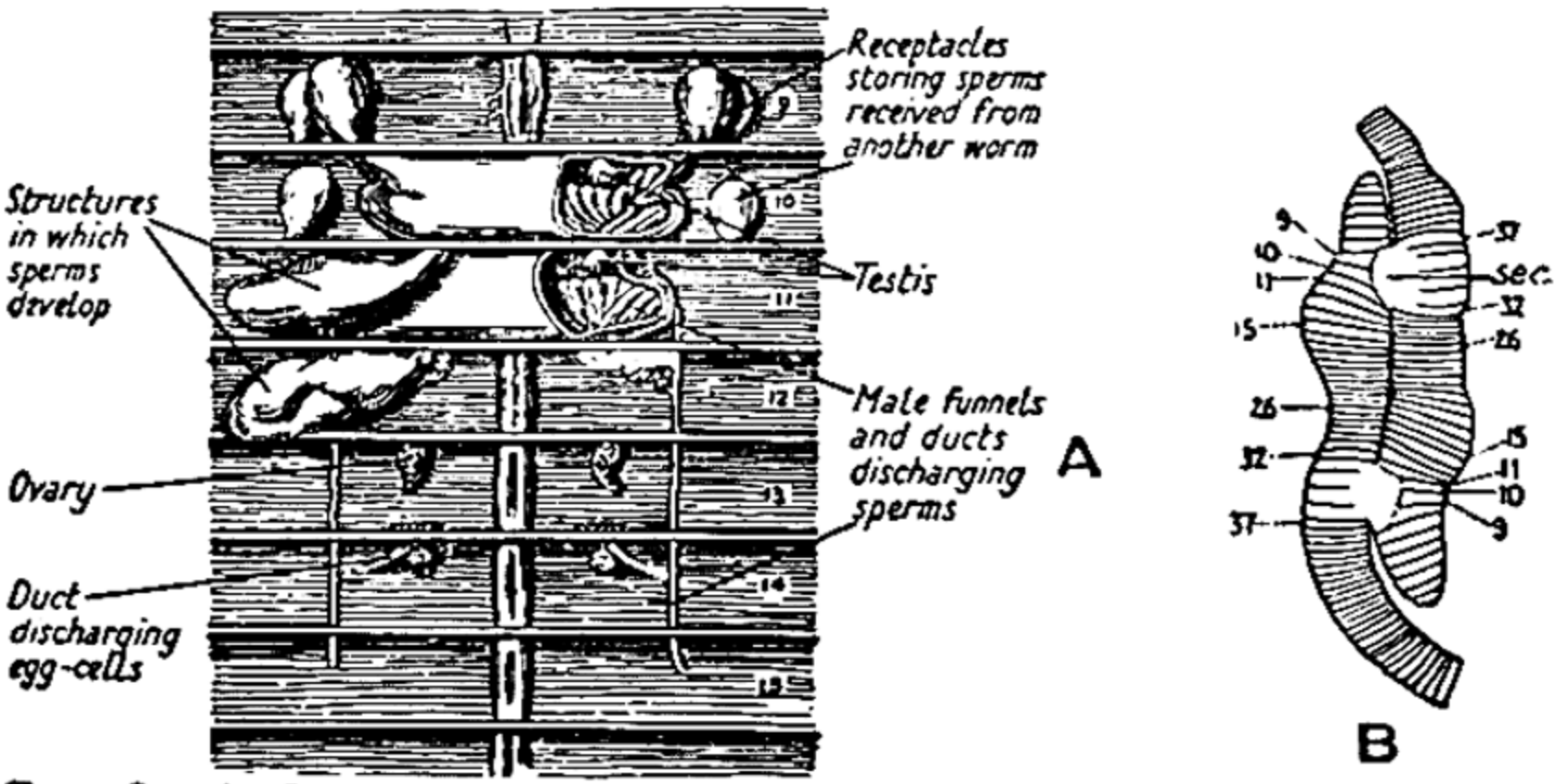


Fig. 162. A. Segments 9–15 of earthworm opened to show reproductive organs (diagrammatic). **B.** Exchange of sperms between two worms (the numbers refer to segments)

four special receptacles, tiny sacs (spermathecae) which open to the exterior. Here the sperms are stored until required. Later a substance is secreted by the clitellum which gradually hardens into the egg-capsule (cp. Fig. 159 B). The worm now wriggles out of this, depositing in it *egg-cells* from its own ovaries and *sperms* (of another worm) from its spermathecae. Fertilization follows in the capsule. Thus the worm, although hermaphrodite, is not self-fertilizing.

Several embryos begin to develop, but one soon outstrips the rest, and only one young worm finally emerges from each capsule.

We may now turn from these lowly creatures to see how the young are cared for among the higher animals.

REPRODUCTION IN CERTAIN VERTEBRATES

REPRODUCTION AND PARENTAL CARE IN BIRDS. Every one knows that most birds build nests, lay eggs, sit on those eggs to keep them warm (i.e. to incubate them), and feed and care for the nestlings for some time after they are fledged. The care of the young has reached a high level in this group.

Exercise. Study for yourself the nesting habits of some of our common birds—e.g. sparrows, pigeons, rooks, blackbirds, starlings, thrushes, swallows, gulls, &c.

Keep a careful written record of your observations. The following questions will help you in this task.

1. When was the bird first observed?
2. Did it appear to have a mate?
3. When did you first see the nest?
4. Where was it placed?
5. Of what materials was it built?
6. When did you first see eggs in it? (Approach very carefully, after this, or you may find the nest deserted on your next visit.)
7. Do both parents sit on the eggs, or only one?
8. Does one parent feed the other while sitting?
9. Is the nest ever left, both parents being away simultaneously?
10. On what date did the young birds appear?
11. Describe the appearance of these nestlings.
12. How are they fed?
13. On what date did they first fly?
14. Did they ever return to the nest after that first flight?
15. Did they resemble their parents in appearance?

The development of a bird's egg is, perhaps, most easily followed in the domestic fowl. If you have access to an incubator you can examine some stages of this development.

EXAMINATION OF THE HEN'S EGG.

Exercise. Carefully break a raw egg into a flat glass dish. Examine it, and notice:

1. The egg-cell or yolk, enclosed in a transparent vitelline membrane. If we prick this, the yolk flows out.
2. A small whitish speck on the yolk. This is the embryo chick. If the egg has been fertilized the egg-cell has already begun to divide.

3. The white, containing two thicker cords, which serve to suspend the yolk so that the embryo always lies uppermost in the shell.
4. The tough parchment-like double skin lining the shell. Notice that this is not in direct contact with the shell at all points. There is an air-space at the blunt end (cp. Fig. 163).
5. The shell itself, which is porous and admits air. You will remember (cp. p. 358) that all creatures require air for growth.

N.B. Eggs are often preserved by immersing them in a fluid (e.g. 'water-glass') which renders the shell impervious. Can you explain why this helps to preserve the egg?

FORMATION OF THE BIRD'S EGG AND GROWTH AND DEVELOPMENT OF THE EMBRYO. The reproductive organs of birds are formed on the usual vertebrate plan, the essential parts being testis and *vas deferens* in the male, ovary and oviduct in the female. In most animals these organs are paired (cp. Figs. 104, 162, 166). The female bird, however, has only one ovary and one oviduct, those of the left side, the structures of the right side being vestigial (cp. p. 471). This may be connected with the fact that the egg-cells of birds are the largest cells known.

The egg, as it leaves the ovary, consists of a single large cell (the yolk), containing an abundant store of reserve food. The yolk of a hen's egg, for example, is 34 per cent. fat, 16 per cent. protein. This egg-cell has a single nucleus, surrounded by a little clear protoplasm, and it is this nucleus which is fertilized by a sperm. The white or albumen, which is chiefly a reservoir of water, the shell membranes, and finally the shell itself are all laid down, after fertilization, by the wall of the oviduct as the egg-cell passes to the exterior (cp. p. 430).

Fertilization takes place in the upper region of the oviduct, and the egg-cell begins at once to divide. These divisions do not involve the whole substance of the cell, but affect only the nucleus and the formative protoplasm round it. Hence the early embryo consists of a small disk of cells, lying on inert yolk which supplies it with food. The first stages of development are over before the egg is laid; at the moment of laying, the embryo of the domestic fowl is already in the gastrula stage (cp. p. 389), and is usually about 5 mm. in diameter. It appears as a white disk on the surface of the yolk.

Incubation of the egg. The egg, as we have seen, contains food and water, and is so constructed that the embryo can obtain a supply of air. Hence three of the conditions necessary for growth are satisfied. But birds are warm-blooded animals, and their eggs must be kept at a fairly high temperature if the

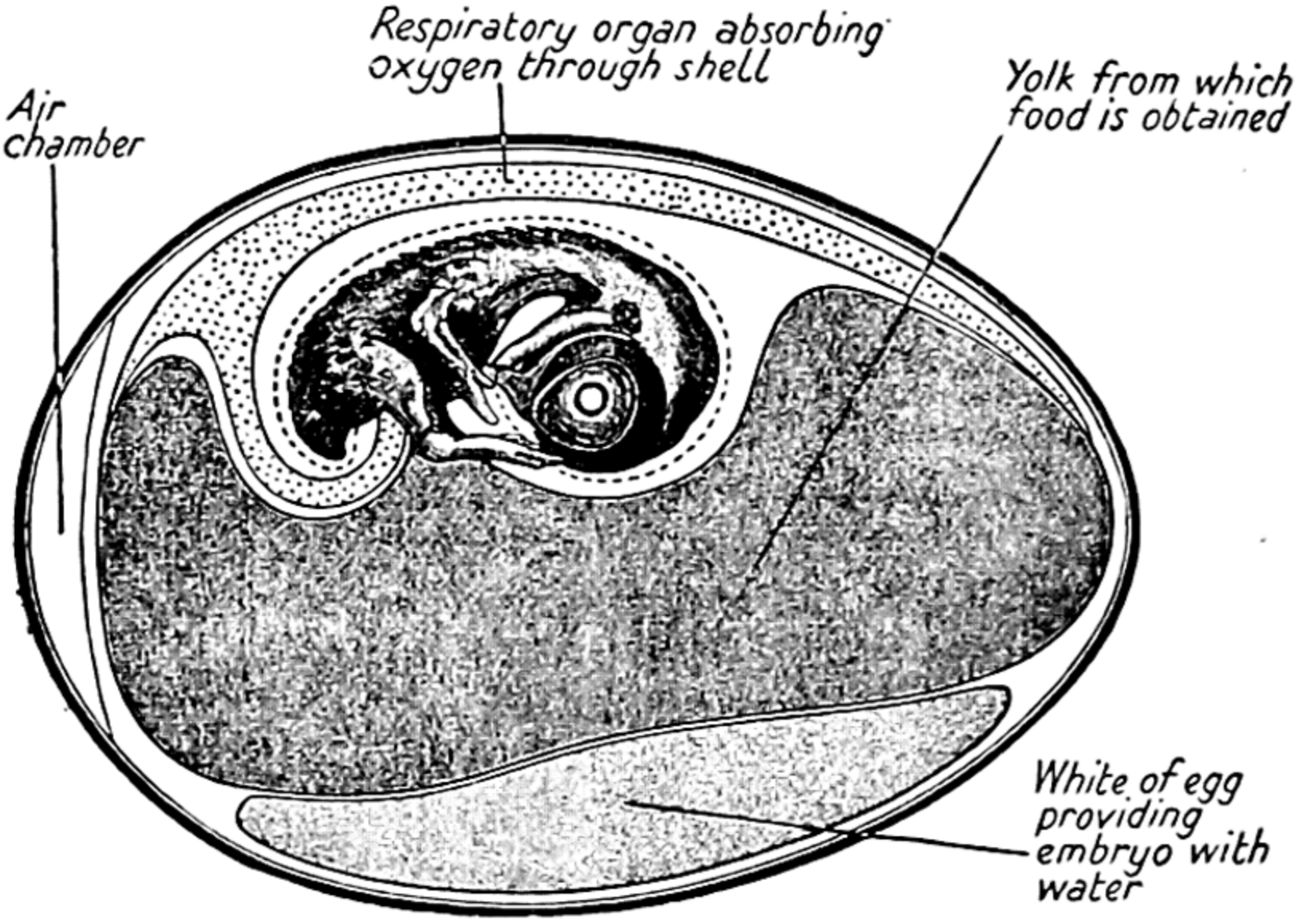


FIG. 163. Hen's egg at the end of ninth day of incubation

contained embryo is to develop. For this reason the bird sits on its eggs; only under these conditions will further development outside the body of the parent occur, and if the egg grows cold after incubation has begun the embryo is almost inevitably destroyed.

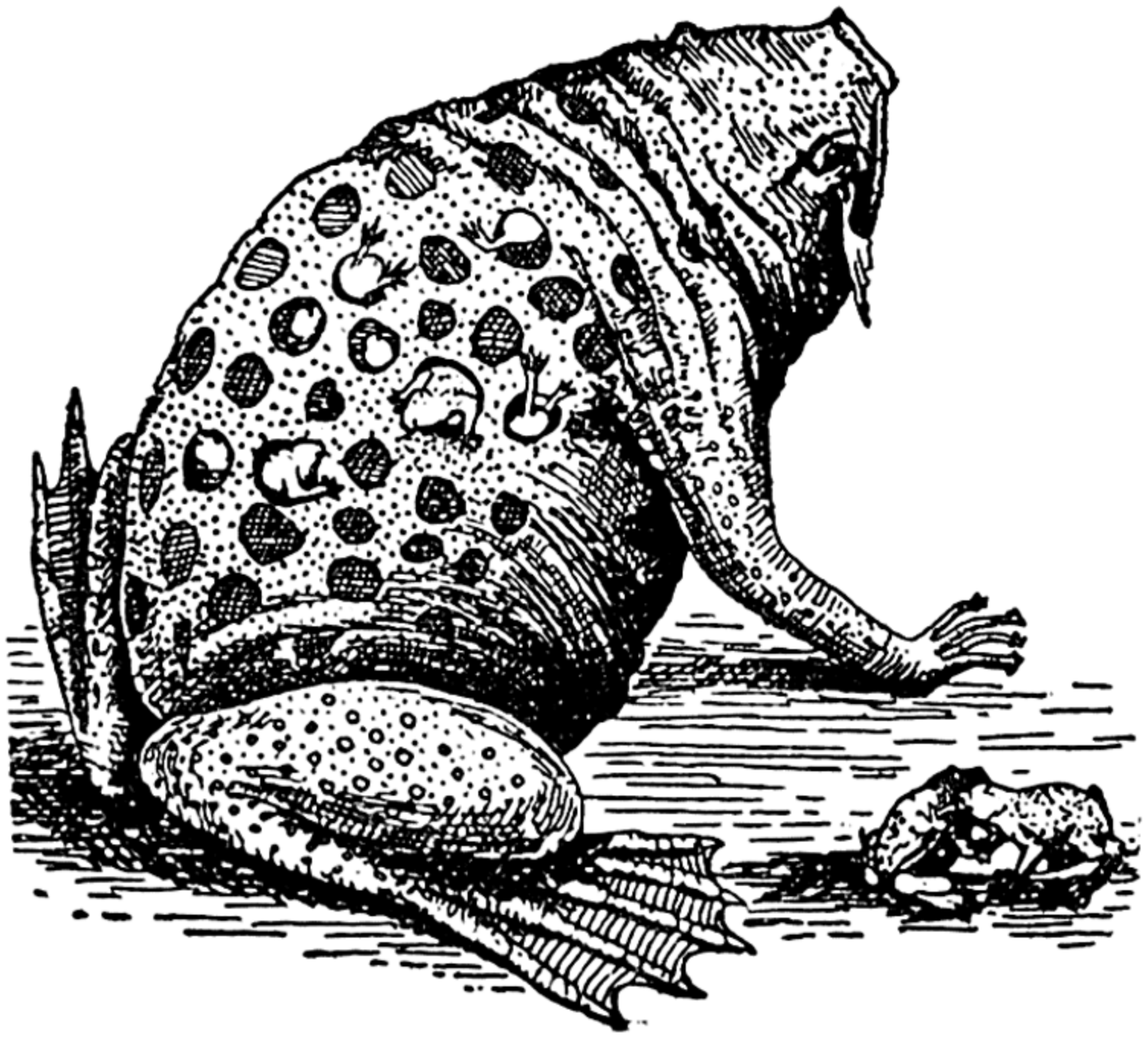
Further growth of the embryo. Development of vertebrate characters. During the first day of incubation the gastrula becomes a three-layered embryo (cp. p. 390); soon the various organs—a dorsal, hollow nervous system, gut, heart and circulatory system, sense organs, &c.—begin to be formed. The heart starts beating during the second day of incubation, vestigial gill-slits are formed which never become functional (cp. p. 516), oxygen being obtained by diffusion through the shell. The stored

food provides the materials for growth and respiration, and the amount of yolk and white diminishes as the chick grows larger. By a system of foldings and intuckings the connexion between the embryo and the underlying yolk gradually becomes narrower. Later limb-buds appear which grow into wings and legs respectively (cp. Fig. 163); step by step the embryo develops into a fluffy chick.

The escape of the chick from the egg. A hen's egg must be incubated for 21 days; at the end of that time you may hear the chick 'peeping' within its shell. By the aid of a sharp-pointed egg-tooth on its upper beak it breaks its shell and escapes. This tooth, having done its work, is soon discarded.

Artificial incubation. On modern poultry farms the eggs are often hatched out in incubators. These artificial 'foster-mothers', if well tended, give more certain results than the best of mothers, for the conditions can be more absolutely controlled. The temperature is more constant, and, by sprinkling water over the eggs daily, one of the chief causes of 'infantile mortality' in the fowl world is averted, namely, water-shortage. The amount stored within the egg is apparently only just enough to meet the needs of the embryo, and if the loss by evaporation through the shell is too large the chicks die in the last days of incubation.

THE LIFE OF THE YOUNG CHICK. CONTINUED MATERNAL CARE. Soon after its escape the little chick will run about and pick up its own food. But it still stays by the mother. We all know her warning 'cluck'; how she keeps her brood near her; how she chases them if they attempt to wander too far afield. Her care is greatly needed; for, although the chick comes into the world with many fully developed instincts, it still has much to learn (cp. p. 223). Experiments show that chickens reared in an incubator do not 'instinctively' respond to their mother's cluck, they have to learn the meaning of the sound. They do not 'instinctively' recognize water, but though thirsty will walk through it without making any attempt to drink, until, by the aid of a moistened finger-tip, or even by a chance peck at their own moist feet, they learn its thirst-quenching properties.



A



B

FIG. 164. Two animals which carry their young in pouches. **A.** Surinam toad. **B.** Kangaroo. (pp. 505, 506)

Similarly, they do not at first know suitable from unsuitable food; some chicks, raised in an incubator, greedily swallowed 'worms' of red worsted! All this, and much more, the mother doubtless teaches them, and her desire to teach and their instinct to learn must save them from many disasters.

PARENTAL CARE IN BIRDS. A SUMMARY. We may summarize the care bestowed upon the young of birds under three heads:

1. The purely physiological devices of stored food and water, protective membranes and shells, &c.; we may find parallel devices even among plants (cp. p. 449).

2. Nest-making, the incubation of the eggs, and the feeding of the young, the food given often being swallowed and partly digested by the parent bird before it is fed to the young nestling (cp. pp. 492, 494).

3. The ability of the young to profit by parental training and to learn from experience.

'One quality above all others must be inseparable from parenthood; ability to learn, anxiety to be taught. The parents to possess are those who "die learning".' (Mary Adams, *Six Talks on Heredity*.)

It is in the ability to learn that animals show the greatest advance as we ascend in the scale (cp. p. 217). Experiments have proved that bees, ants, even spiders can learn to some extent; but they do so with difficulty and the lessons are soon forgotten. Their life is guided almost entirely by instinct. The higher animals, e.g. birds, have these instincts too, but they have more intelligence. But the intelligence even of birds must not be over-estimated. Many of their most specialized activities, migration for example, seem to be almost entirely instinctive. A cuckoo which has never seen its parents and has been reared in England by non-migratory foster-parents can hardly have any picture of Africa or any reasoned purpose for setting off on so long a journey (cp. p. 397). What are we to think of the intelligence of a pair of meadow-pipits who continue to feed an infant cuckoo after he has killed their own children by turning them out of the nest? Or of the mentality of a hen who is deceived by a chalk egg? Such facts show us how limited is a bird's intelligence.

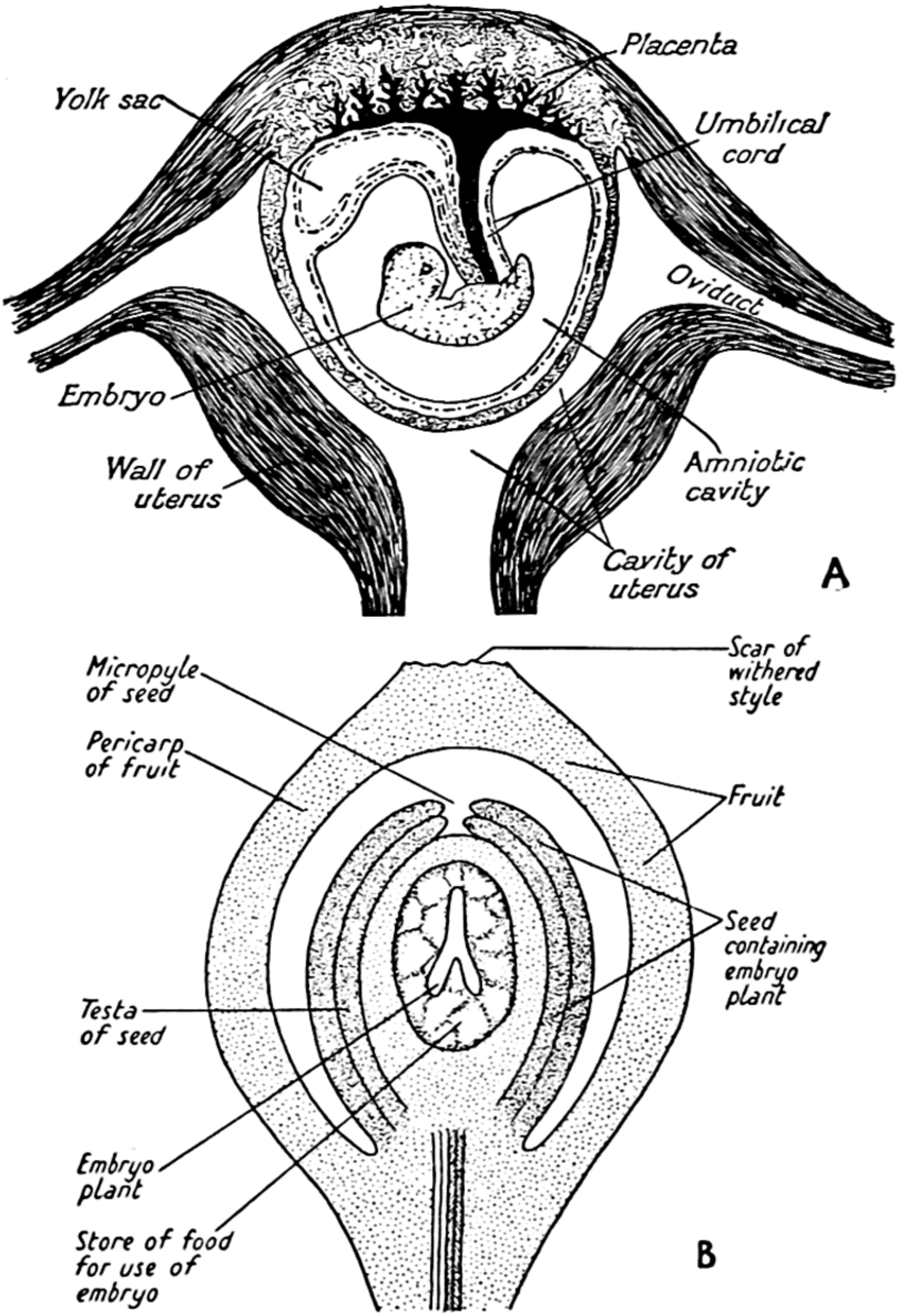


FIG. 165. COMPARISON OF PROTECTION AFFORDED TO EMBRYO IN FLOWERING PLANT AND MAMMAL. **A.** Mammalian uterus containing developing embryo. This is attached to the wall of the uterus by the placenta and umbilical cord. **B.** Fruit and seed of flowering plant with developing embryo. The embryo is not attached to the parent organism, but lies surrounded by food supplied by the parent

'The sight of a pigeon brooding on an empty nest, while her two eggs lie unregarded only a couple of inches away, is enough to show that along certain lines, birds may find it impossible to get free from the trammels of instinct.' (*Outline of Science.*)

A STILL MORE EFFICIENT METHOD OF PROTECTING THE DEVELOPING EMBRYO. However careful a parent bird may be, however brave in the defence of her nest, the eggs are not easily protected, for they cannot be moved quickly when danger threatens. Probably you have at some time collected birds' eggs; you would have found it far more difficult to catch the live birds. Eggs are very vulnerable. The embryos would obviously be better protected if they were attached to the mother, so that she might take them with her wherever she goes, as does the Lycosa wolf-spider (cp. p. 495). We find many devices in animals by which the eggs can be permanently attached.

Brood-pouches. Sometimes they are carried in special brood-pouches, which are a part of the body of the parent. The little Cyclops, for example, so common in every freshwater aquarium, has tiny egg-bags, within which the eggs are carried until they hatch. She cannot drop her eggs as does the spider, for the brood-pouches are a part of her body. Among sea-horses the father has the pouch, and he puts his wife's eggs into this 'breast-pocket', carrying them about in security until they are hatched. In the Surinam toad the male helps to press the eggs, directly they are laid, on to the back of the female, where each sinks into a little pocket in the skin, to remain there all through its early development (cp. Fig. 164 A).

The emperor penguin, the largest of the penguins, also has a pouch in which the egg is placed.

'During the period of incubation, which duty is shared by all, male and female alike, the egg is held in a loose fold of skin at the lower part of the abdomen, the skin of the adult being worn bare of feathers in this region.' (G. Murray Levick, *Antarctic Penguins.*)

Many such examples could be given. Best known of all are the brood-pouches of certain very primitive mammals, the

marsupials or *pouched mammals*, of which the kangaroo is a well-known example. It is not an egg, however, but a tiny, undeveloped embryo kangaroo, helpless, unformed, and barely an inch long, which is first placed in the pouch; it is put there immediately after birth by its mother. Too undeveloped to suck, milk is forced down its throat by contraction of a muscle attached to the mother's milk gland, and the tiny creature remains in the pouch (*marsupium*) until it is far enough advanced to lead an independent life (cp. Fig. 164 B).

Retention of the egg within the oviduct. The most efficient of all mechanisms for the protection of the young is the retention of the embryo within the mother's body during the earliest and most precarious stages of its existence. This is what happens in the flowering plant (cp. Fig. 165). We find this same method of protection in some quite lowly animals, for example, among greenfly. During summer these give forth minute living greenfly at the rate of two or three a day; they are produced from egg-cells which develop internally and without fertilization (parthenogenetically), the little creatures being born alive. The viviparous pond-snail is another familiar creature which produces living young instead of depositing eggs in the form of spawn. *Vivipary*, or the birth of live young, is seen in many vertebrates, e.g. many sharks, snakes, &c. In such cases what usually happens is that a large yolk-laden egg passes so slowly through the oviduct that the embryo develops there to the point of hatching, and the young creature leaves the oviduct 'alive'.

REPRODUCTION OF THE MAMMAL. It is among mammals that we find this form of parental care most highly developed (cp. Fig. 165). The young are kept for a long time before birth within the shelter of the mother's body, where they are fed and protected until they are ready to be born, i.e. to begin their independent existence.

UTERUS AND PLACENTA. The egg-cells of mammals are very small; that of a rabbit, for example, is 1/100 of an inch in diameter at the time of fertilization, the human egg-cell being about 3/100 of an inch across. No food is stored in this egg, for not only does the embryo develop internally, so that it is warm

and well protected, but it also obtains its nourishment from the mother. For this purpose, while still in the blastula stage (cp. p. 389), the embryo, as it passes down the oviduct, becomes attached to a specialized and enlarged portion of that duct, called the uterus or womb. A special organ, the *placenta*, is

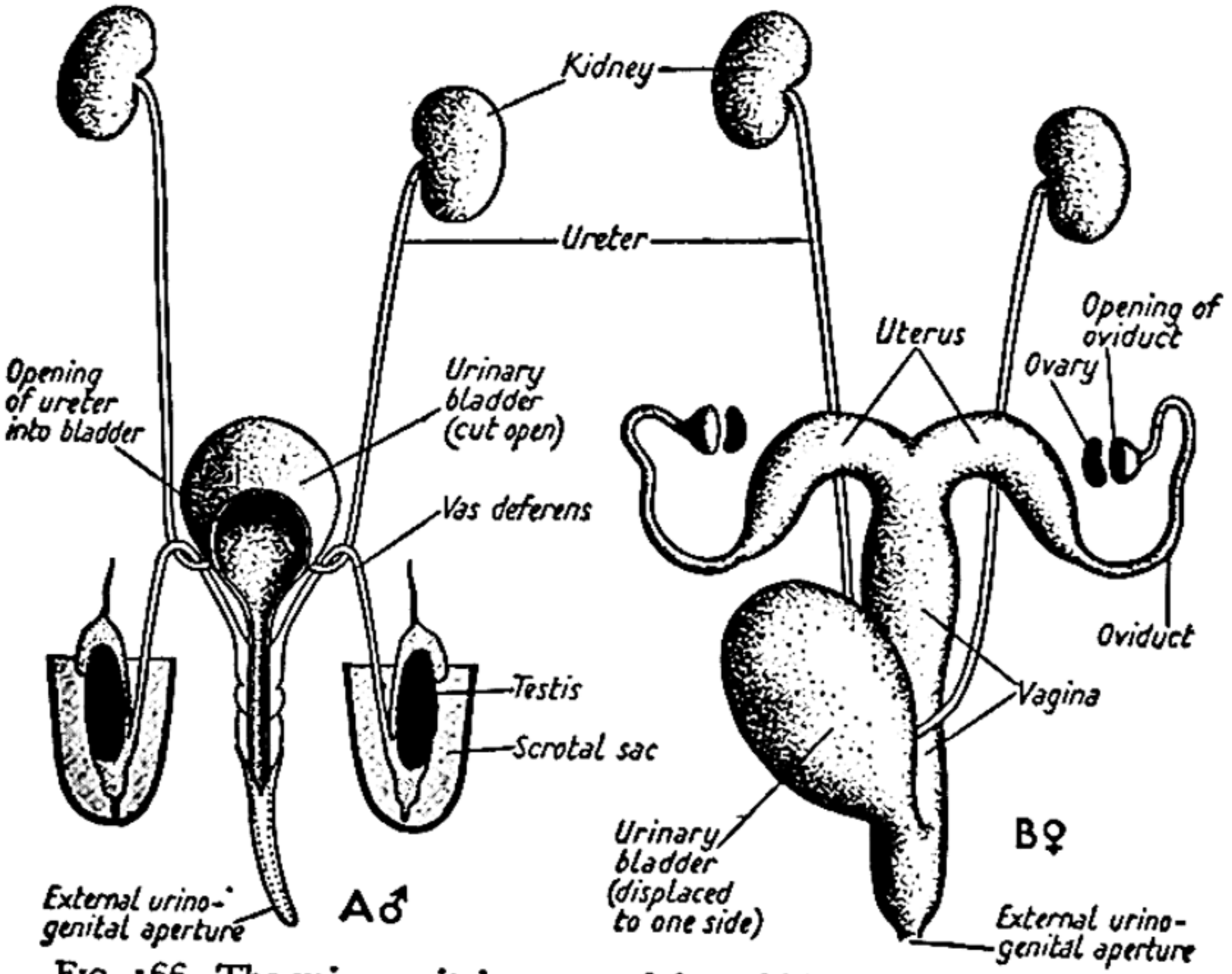


FIG. 166. The urinogenital organs of the rabbit. **A**, male; **B**, female

formed at the point of attachment (cp. Figs. 165 and 167). This placenta consists partly of maternal tissue, partly of a special outgrowth from the embryo, called the *allantois*. A similar outgrowth is formed in embryo birds, &c., where it is used for respiration and excretion (cp. Fig. 163). The blood-stream of the mother flows through the placenta as does that of the embryo. The two circulations are only separated by thin-walled capillaries, and diffusion takes place freely between the maternal and foetal blood; all materials required by the embryo—food, oxygen, &c.—are obtained from the mother's blood as it circulates in the placenta, and any waste matters

excreted by the foetus, as the young animal is now called, are removed in the same way.

Warm, well protected, and well nourished, the young

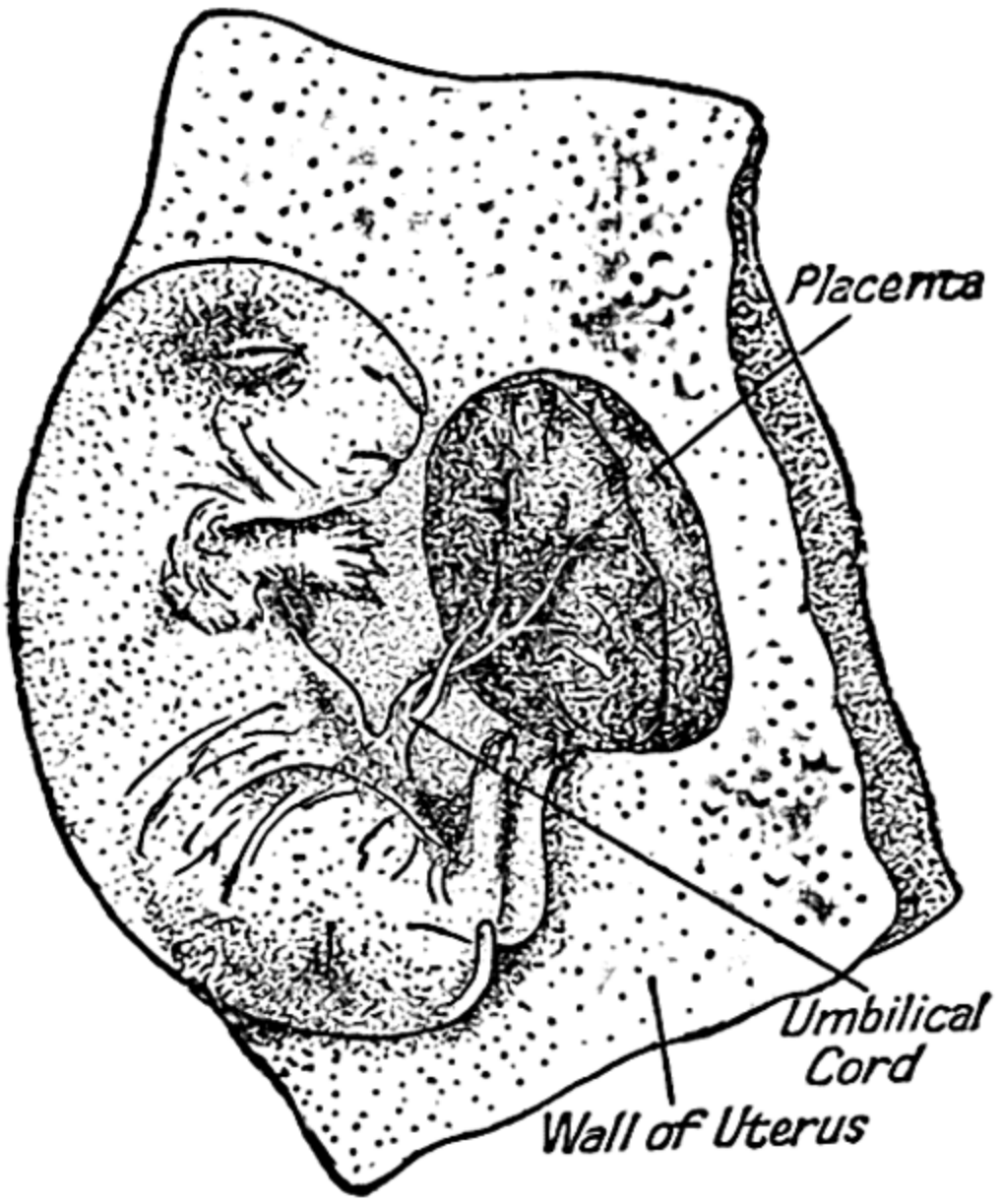


FIG. 167. Uterus cut open to show the rabbit embryo before birth

creature develops continuously until the time comes for it to be born.

POST-NATAL CARE. After birth the infants are cleaned and cared for by their parents, and fed on milk produced by the mammary glands. This milk (cp. p. 55) is specially adapted to the needs of the young animal.

Passing from the lower to the higher mammals, we find that the period of infancy becomes proportionately longer; this gives opportunity for the training and education of the young, and it is also in such forms that we see parental care at its best and highest. Father-love comes to supplement mother-love, and the young creature is well trained and well equipped before it is left to face life alone.

REPRODUCTION AND REPRODUCTIVE ORGANS IN THE RABBIT. The rabbit is a typical mammal; let us examine its reproductive organs.

Exercises

Examine and draw a dissection of a rabbit which displays the female reproductive organs. Notice the two small ovaries, and the two oviducts. The lower part of each oviduct is somewhat enlarged; this is the uterus or womb, within which the young animals develop. In the rabbit there are two such organs; many mammals have only one (cp. Figs. 165 A, 166 B).

Examine similarly a dissection displaying the male reproductive organs. Notice the paired testes in the scrotal sacs, the two narrow *vasa deferentia*, and the penis where they open (cp. Fig. 166).

THE LIFE OF THE FOETUS. The egg-cell of the rabbit is very small, but the sperm, which consists of a head and a motile tail, is even more minute. The developing embryo soon becomes attached to the wall of the uterus, where it remains for from thirty to thirty-two days (the period of gestation), growing all the time, until, when it is born, it has become a small, fully developed but still very helpless, baby rabbit.

THE LIFE OF THE ADULT RABBIT. Rabbits, which occur wild on both sides of the Mediterranean, are believed to be not truly British, but to have been introduced, possibly from Spain, and probably in early Norman times.

How rapidly these creatures will invade any favourable area is illustrated by the well-known story of their spread in Australia. Originally only three pairs were introduced, but they soon became a terrible plague, devouring grass, the bark of trees, and, of course, the crops of the unfortunate settlers. During the 'slump' of 1929–33 much land painfully reclaimed by man from the wild was invaded and completely overrun by rabbits, and this in spite of their wholesale destruction. (From New South Wales alone an average of fifteen million rabbit skins are exported every year.) Twenty years after rabbits had first been introduced into New Zealand, twelve million skins were being exported annually, and yet the destruction they caused was so great that the colonists had to adopt special measures to combat this plague.

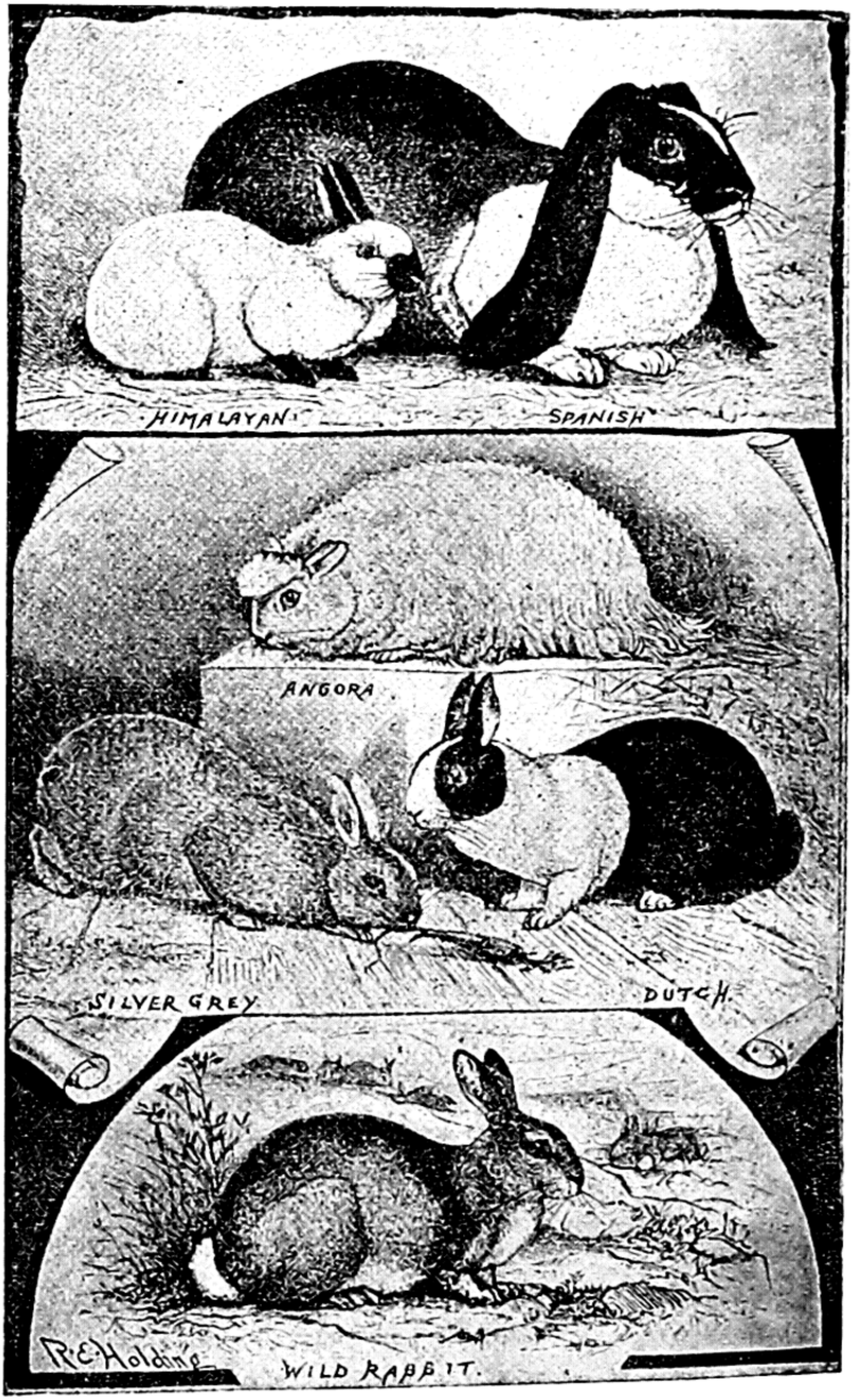


FIG. 168. Races of the rabbit (from Romanes)

Rabbits are about 16½ inches long when full-grown, and weigh between 2¼ and 3 lb. They can run at great speed, can swim and climb. They are gregarious in their habits, preferring sandy soils, especially those covered with gorse or heather. They burrow into the soil (unless this is too wet, when they make runs among the vegetation), the burrows having two entrances. They penetrate the ground in all directions, forming the well-known rabbit warren. The inhabitants of this warren are said to warn each other of approaching danger by thumping on the ground with their heels. If one puts one's ear to the ground it is sometimes possible to hear the vibrations so produced.

PARENTAL CARE BY THE MOTHER RABBIT. The young are born and nursed in a special excavation to which there is only one approach. This is prepared by the mother, and in it she forms a soft nest of grass and her own fur. When born these infants are naked, blind, and helpless. The mother (doe) soon begins to leave them alone by day, closing up the entrance to the nest with earth; she returns at evening to suckle them. They soon become self-reliant and can get their own food. Even when very young these animals have an excellent sense of locality. They never seem to lose their way, but always keep an eye on the entrance to the burrow, and are ready to beat a hasty retreat if danger threatens. At six months they are mature and may become parents in their turn. Four or five litters may be produced each year, and as there are from 5 to 8 young in each litter, it is not surprising that, when conditions are favourable, rabbits increase at an amazing rate.

THE RABBIT IN INDUSTRY. Not only is this animal much used for food, but the rabbit-fur industry is a very valuable one, and many special strains (some 3,000 varieties are known) have been produced by the breeders, of which about twelve are of commercial importance—e.g. martin, sable, chinchilla, angora, silver queen, &c. Six great auctions of rabbit skins are held in London annually, at which approximately 200,000,000 skins are sold, London having become the most important market for this trade.

QUESTIONS ON CHAPTER XXXVI

1. Describe any personal observations you have made in connexion with the development of a butterfly (or a moth) from the laying of the eggs to the emergence of the perfect insect. (L.G.S.)

2. Give an account of the changes that take place during metamorphosis in the butterfly and the frog, and show how the changes are associated with the changes in the method of locomotion and of obtaining food. (L.G.S.)

3. Describe the tadpole of the frog, and give an account of the phenomenon of metamorphosis. What deductions may be drawn from this life-history as to the evolution of vertebrates? (L.G.S.) (Cp. Chapter XXXVII.)

4. Give a short illustrated account of the development of the frog from the egg-cell, and briefly compare this development with that of the chicken within the egg. What are the greatest differences between the two methods of development? Discuss how these are related to the different environments in which the young animals develop.

5. Write a short illustrated account of the life of any social insect you have studied, and show how the insect community cares for its immature young.

6. Give an account of the external features and mode of life of any bird with which you are acquainted.

7. Write a short essay on parental care as exhibited by (*a*) any two named plants, (*b*) any two vertebrate animals.

8. Describe in general terms the development of a flowering plant, from the fertilization of the egg-cell to the establishment of the self-supporting seedling. Briefly compare this development with that of the young mammal, explaining how the latter is nourished both before and after birth.

9. Compare the development of the ovule into the seed with the development of the newly laid hen's egg into an egg at the end of incubation. What similarity is there between the two processes?

10. Write a short essay on Reproduction, giving illustrations from both animal and vegetable kingdoms. (L.G.S.)

11. What are the essential features of reproduction? Illustrate your answer from any animal types with which you are acquainted. (C.L.)

12. In nature one generation succeeds another; explain how in both plants and animals provision is made for the success of the new generation. (L.G.S.)

CHAPTER XXXVII

EVOLUTION AND HEREDITY. BIOLOGY IN THE SERVICE OF MAN

'In nature's infinite book of secrecy a little I can read.'

THE THEORY OF EVOLUTION. One of the most fertile concepts that biologists have given to the world is the idea of evolution.

'It is a master-key that opens many doors. It is a luminous interpretation of the world, throwing the light of the past upon the present. Everything is seen to be an antiquity with a history behind it—a natural history, which enables us to understand in some measure how it has come to be as it is.' (J. Arthur Thompson, *Outline of Science.*)

The idea is no new one. We find it expressed by some of the Greek philosophers, and by many thinkers since that time. What do we mean by it? Simply that living organisms when they first appeared on the earth were not like those of to-day. Living creatures have gone through a long process of becoming, of change (evolution), since they were first formed.

We generally picture evolution as a process by which organisms become increasingly well adapted to their conditions (cp. p. 272), and which enables them to adjust themselves to a changing environment. One result of the process, for example, has been that plants and animals which once lived in water gave rise, in the course of time, to descendants able to live on dry land. There is much evidence (e.g. the vestigial gills formed in the embryos of all vertebrates (cp. p. 500), the motile male cell formed in the pollen tube of some primitive seed-plants (cp. p. 447)) that the land-inhabiting creatures of to-day come from forebears who lived in water (cp. p. 326). Evolutionary changes generally involve a progressive advance in structure; life creeps slowly upwards; it becomes fuller, fitter, and more free. Leaves become better assimilating organs, gills better adapted for absorbing oxygen from water, brains better organs for co-ordination and control. We have seen how much more efficient as oxygen-absorbers are the lungs of

a mammal than those of a frog (cp. p. 295); how the brain of the mammal makes it capable of a much fuller life than is possible to the frog with its inferior brain (cp. p. 217). In evolutionary language the mammal is a 'higher' animal than the frog, it has advanced farther along the path of progress.

We must not, however, lose sight of the fact that the movement is not always upwards. The advance has been chequered. Some creatures remain primitive, e.g. the many unicellular organisms; others, as the fossil records show, reach a certain level and then go on unchanged through countless ages; still others slip backwards and become degenerate. This is well seen in those flowering plants which return to the water (cp. p. 272). Root, conducting system, stomatal apparatus, all tend to disappear. Parasites often show extreme adaptation to their mode of life. Dodder, for example (cp. p. 192), is a flowering plant, yet it possesses no chlorophyll, vestigial leaves, and only a transitory root which does not outlast the seedling stage. It has apparently lost these organs in the course of evolution.

THE COMING OF EVOLUTION. Although the idea of evolution has occurred again and again in the thought of the world, only in the second half of the nineteenth century did it gain popular acceptance. It was applied first to explain the origin of the solar system and of our world, one of the smaller planets of that system. Next DARWIN and others applied it to animals, including man, and in his great book *On the Origin of Species by Natural Selection*, published in 1859, Darwin marshalled such conclusive evidence that animals and plants undergo evolution, that the idea gradually found favour, and the date 1859 marks an epoch in the history of modern thought. The theory is accepted in its broader features by practically every biologist, for nothing else gives such a reasonable explanation of the facts which biology reveals. Evidence in support of the theory is still being accumulated. Further, the idea has not only revolutionized man's conception of himself and his place in the universe, but it has illuminated many other fields of thought. We speak, for example, of the evolution of civilization, of language, of custom, of democratic ideals, of moral ideas, even of religion.

'This realisation of ourselves as we truly are—emerging with difficulty from an animal origin, tinctured through and through with the self-regarding tendencies and habits it has imprinted on us, this realisation or self-knowledge is humility, the only soil in which the spiritual life can germinate.'

Such a sentence, taken not from a text-book of biology, but from E. UNDERHILL's *The Life of the Spirit in the Life of To-day*, shows clearly how thoroughly this biological concept of evolution has permeated even religious thought. What is the evidence on which this theory rests?

EVIDENCES OF EVOLUTION

I. FOSSIL EVIDENCE. Perhaps the most convincing of all the evidence for evolution is that derived from fossils. If we examine the earth's crust we find in it the fossilized remains of many plants and animals. Most of these are unlike any creatures which exist to-day, and, moreover, the farther back we go and the older the rocks we examine, the less like modern organisms do the fossils become.

The coal-measures, for example, contain the remains of many plants, but these were giant ferns, club-mosses, horse-tails, and seed-plants of a very primitive kind, while in the forests of that far-off carboniferous age no fossil of any vertebrate higher than an amphibian occurs.

These were succeeded by the great reptiles whose skeletons are such familiar objects in every natural-history museum. With them came a new flora, containing many primitive seed-plants (cp. Gymnosperms). True flowering plants (Angiosperms) had still not arrived.

What can be more eloquent than this general fact that the older the rocks, the lower in the scale are the creatures contained therein? Mammals and birds appear only in comparatively recent strata, while on the plant side flowering plants are the last to appear. Furthermore, among such fossilized remains are many most interesting transitional types, flying reptiles (pterodactyls), for example, and reptile-like birds.

Archeopteryx, whose remains were found in Bavaria, was a creature with teeth in both jaws (no modern bird has teeth), with a long reptilian tail, with a wing only partially developed as a flying-organ, a wing still provided with a thumb and two fingers, all clawed (cp. Fig. 133). Yet it had feathers, and was undeniably a bird.

Many other curious creatures have been unearthed, and they all tell the same tale. We are driven by such evidence to believe that we ourselves and the creatures known to us, both plant and animal, have evolved from some of those far-off forms by a process of more or less gradual change and differentiation.

When considering this argument it is well to remember that we are continually witnessing the development of new types of cultivated plants and domestic animals. Dogs, sheep, cattle, fowls, pigeons, wheat, roses, apples, &c., have all been purposely developed by man from very different ancestors.

II. EVIDENCE FROM CLASSIFICATION. The likenesses between living things, the fact that they can be arranged in groups, each with its own fundamental plan, can also be explained if we believe in evolution.

We have seen that underlying the great diversity of flowering plants lies the same general plan (cp. p. 19), that in all vertebrate animals the skeleton, digestive organs, the nervous, excretory, and reproductive systems, are fundamentally alike (cp. pp. 161, 216, 332, 403). These likenesses are easily understood if we hold the view that, could we but trace the generations back into the distant past, we should find that each such group was descended from the same ancestral stock.

III. EMBRYOLOGICAL EVIDENCE is also very strong. A chick within its egg-shell, a mammalian foetus in the womb, develop functionless and reduced (vestigial) gills (cp. p. 500). Why is a frog first a fish-like form with fins and a tail, before it is a tailless, lung-breathing adult with pentadactyl limbs? Is it not because it is recapitulating, to some extent, the story of its race? Are we not driven to believe that it is descended from ancestors which were in many respects like fishes; in short, to believe that the frog is the result of a process of evolution? And will

not the same argument account for the vestigial gills in the embryos of birds and mammals, &c.?

IV. VESTIGIAL STRUCTURES also occur in the mature organism and tell the same tale. Man has a vestigial appendix and a vestigial tail (cp. Figs. 42, 127). The horse walks on one toe only, but has two additional vestigial toes, and fossilized remains of five-toed horses have been found. Whalebone whales have two sets of teeth, which never even cut the gum. The fowl has a vestigial second ovary (cp. p. 499). The ostrich, a flightless bird, has small and useless wings. Vestigial leaves are found on a potato tuber (cp. Fig. 118) and on the dodder and broomrape stems (cp. Fig. 49), very reduced conducting tissues in many aquatic flowering plants (cp. p. 272). Countless examples of such vestiges are known. In man at least seventy have been described. Vestigial organs are generally useless and may be troublesome. Caecum and appendix are useful to a rabbit (cp. p. 174), but the appendix is a common source of disease in man. Is there any more rational explanation of such useless vestiges than that which the theory of evolution offers?

V. HOMOLOGOUS ORGANS tell the same tale. The limbs of all vertebrates above the fishes are formed on the same plan, although used for many different purposes. Underlying a man's hand, a bat's wing, a horse's foreleg, and a whale's paddle is a bony skeleton which is strikingly similar in them all; the same bones and the same muscles, but used for very diverse ends. If created specifically for these ends, one would not expect this similarity. It is accounted for if we accept the theory that they are all modifications of the same ancestral organ—the so-called pentadactyl limb (cp. Fig. 131); these modifications having arisen in the course of evolution, as the limbs were made to serve different purposes.

VI. THE FACTS OF DISTRIBUTION support the same view. For example, when Australia was discovered by white men there were no placental mammals except a low race of men, their dogs, and a few bats. But it was very rich in marsupials, such as the kangaroo (cp. p. 502), which group is undoubtedly more primitive. There are many such facts which are difficult to explain on any theory of special creation.

All this evidence, taken together, each fact reinforcing all the others, is fairly conclusive. Let us summarize it:

i. There is the fossil evidence, i.e. the evidence from history.
ii. The evidence from classification.
iii. ,, ,, embryology.
iv. ,, ,, vestigial organs.
v. ,, ,, homologous organs.
vi. ,, ,, geographical distribution.

We must, however, beware of that error, so common before the days of science (cp. p. 11), of mistaking theories for facts. As scientists, we must continually test and criticize the evidence on which any theory is based, and try to remember that it is only a theory, and may at any time, as new facts become known, be replaced by a more comprehensive one. Science itself must evolve. For example, we do not yet know with any certainty exactly how evolution is brought about, or what are the forces underlying it, though Darwin, Lamarck, and others have put forward very suggestive hypotheses. The theories of a hundred years hence are bound to be different from those of to-day. Yet, in so far as our work has been truly done, they will be built on to-day's theories, to-morrow completing what to-day has begun.

SCIENCE IN THE SERVICE OF MAN

SCIENCE AND CIVILIZATION. In the first chapter of this book we saw that science owed its origin partly to a change in man's attitude towards knowledge. 'This our human experience in its humbling imperfection,' . . . 'Our inevitably limited way of laying hold of the stuff of existence'—these phrases from a recent book illustrate the terms in which the best modern minds are thinking. When man became conscious of the inadequacy of his knowledge he was filled with a desire to add to the common store.

Out of this new spirit of inquiry have sprung all the most distinctive features of European civilization. The inspiration of the modern world is derived from three main sources: from Hebraism, which gave us our religion; from Hellenism, which gave us our distinctive culture; and from modern science,

which has given us our freedom of thought and our material well-being.

SCIENCE AND MATERIAL PROGRESS. We all realize to some extent how much of our material progress we owe to the physical sciences; e.g. all our modern facilities for communication (trains, steamships, aeroplanes, telephones, wireless telegraphy, &c.), and all those labour-saving machines which have so enormously increased production. We often forget how rapidly these new developments have overtaken us. *Puffing Billy* first hauled coal in 1813, and the Liverpool and Manchester railway was opened in 1830. In 1833 the *Royal William* crossed the Atlantic for the first time under its own steam, and the first telegraph messages between England and America went through in 1858. The whole development of our modern machine-made world has taken little more than a century.

BIOLOGY AND MATERIAL PROGRESS. THE CONTROL OF DISEASE. The achievements of biology, though less spectacular, have been equally important. Consider, for example, the advance in medicine, and try to visualize the tremendous effects of our modern understanding and control of disease. During the Middle Ages, even in times when no great epidemic was raging, only one English baby in four survived its earliest infancy. Compare this with recent figures giving infant mortality rates. In England, during recent years, the infant deaths for 1,000 healthy births were as follows:

1893	. . .	155 per 1,000
1900	. . .	139 „
1907	. . .	112 „
1914	. . .	95 „
1921	. . .	74 „
1928	. . .	66 „
1935	. . .	57 „

Think what this means in relief of suffering, both physical and mental, and in saved lives.

Plague, smallpox, typhoid, malaria, and diphtheria are among a few of the maladies which we are now getting under control; the true understanding of these infectious diseases began with the biological work of PASTEUR (cp. p. 434), and

more knowledge is continually being gained. When the first attempts were made to construct the Panama canal, the mortality among the workmen (from malaria, yellow fever, &c.) was so terrible that the attempts had to be abandoned. Then came the discovery of the malarial parasite and of the part played by mosquitoes in its spread (cp. p. 313). This knowledge taught us how to combat malaria, and to-day, according to an American authority, 'the canal zone has a lower death-rate than New York City'.

Over vast areas of the tropics the death-rate from the hook-worm disease alone has been reduced from 25 per cent. of the population to less than 2 per cent. Vaccination, preventive inoculation, injection of an antitoxin, &c., are all modern methods of combating disease where medical men owe a great deal to discoveries in pure biology.

THE REFORM OF SURGERY DUE TO BIOLOGICAL DISCOVERY. It was LISTER (1827–1912), stimulated by the discoveries of Pasteur, who initiated one of the greatest reforms in modern surgery. 'Most hospital surgeons', wrote Sir JAMES SIMPSON in 1869, 'remain content with losing one-third to one-half of *all* their amputation cases, and nine-tenths of some.' In 1870, during the Franco-Prussian war, of 13,173 amputations of all kinds, including many quite minor ones of fingers or toes, which had to be carried out by French surgeons on the field, 10,006 proved fatal. This was due in most cases, not to the amputation itself, but to the after effects, and chiefly to infection of the wound by bacteria. Think of the difference between these results and the great surgical feats performed during the Great War (1914–18).

Lister attacked this subject of wound infection, and his introduction of antiseptic methods, to be followed later by modern aseptic ones, so reduced the mortality from operations that the death-rate in a modern surgical ward, even after abdominal operations, some of which are very severe and are only undertaken as a last resort, is never more than 1·5 per cent.

Pasteur, Lister, MORTON (who made the first successful extraction of a tooth under ether in 1846), and Simpson (who discovered the anaesthetic effects of chloroform in 1847) were

probably the four men who did most to relieve the suffering both of human beings and of animals during the nineteenth century.

THE IMPROVEMENT OF CULTIVATED PLANTS AND DOMESTICATED ANIMALS. We may mention still another field in which biological discoveries have led to great advances. By carefully breeding only from our best stocks, and by applying to cultivated plants and domestic animals our increasing knowledge of the laws of heredity (cp. p. 436), these plants and animals have been greatly improved. Modern cows give, on the average, at least 10 per cent. more milk than they did at the beginning of the century. Work on wheat carried out in Cambridge (breeding wheats which give good yields and are resistant to disease) has added hundreds of thousands of pounds yearly to the wealth of this country. A new wheat recently introduced into the Central Provinces of India, bred to suit the conditions there, is expected to increase the value of the crop in that district alone by £7,000,000 a year. Another new variety of wheat, which is being distributed by the Ohio government plant-breeding station, yields on the average two bushels more per acre than the types grown there hitherto. As in that State there are over two million acres devoted to wheat-growing, the gain, as you see, will be considerable. Many other examples could be given; although the size of the world remains fixed, biological science is teaching us how to make it yield more and ever more food. Practically all our farm animals and agricultural crops have been studied and improved during the present century, while the beauty of our gardens owes much to modern highly bred varieties of familiar garden flowers.

BIOLOGY AS AN INSTRUMENT OF CULTURE. We know that biology has done more for us than increase our material well-being. In giving us the idea of evolution (cp. p. 514) it has transformed our thought, and this has had far-reaching effects on man's view of his own nature, his history, and of his place in the whole universe.

As biological knowledge spreads and people gain a better understanding of its laws we may certainly hope for a healthier, saner, and happier race.

But even this is not all. The hope that man may gradually accumulate knowledge which will help him, to some small extent, to guide his own evolution and so to control his destiny, is one of the most stimulating ideals which has been suggested to the modern world, and this idea emanates from the study of biology.

'Biology', said S. W. Morley Fletcher in a recent broadcast talk, 'is now mature enough to give man definite counsel in many directions, not to replace, but to supplement the older controls of an ethical, traditional and religious character. Biology can advise as to habit-forming, diet, environment, sleep, play, and the whole question of population. When its advice is widely asked and taken a new era will have dawned.'

BIOLOGY IN THE FUTURE. The above words embody the considered opinion of most modern biologists; as the nineteenth century was the age of physical science, so we must make of the twentieth an age of biological science. The problem is embodied in those words 'the whole question of population'. What is the use of improving man's natural environment unless at the same time you can 'improve' man himself? The Great War brought this fundamental lesson home to all of us. 'Science', it has recently been said, 'is a social activity whose object is to make man master of his destiny on earth.' His whole destiny, and not just his material environment.

'What do you think endures?

'Do you think a great city endures?

'Or a teeming manufacturing state? Or a prepared constitution? Or the best built steamships?

'Or hotels of granite and iron? Or any chef-d'œuvres of engineering —forts, armaments?

'Away! these are not to be cherished for themselves.

'A great city is that which has the greatest men and women. If it be but a few ragged huts it is still the greatest city in the whole world.' (Walt Whitman.)

How are we to get those 'greatest men and women'? That is the problem before humanity. The task is, of course, extremely complex; spiritual values, even intellectual values, are not as easy to measure as are the disease-resisting properties

of wheat or the fleetness of race-horses. But even in this great task biology can give us some guidance. It is becoming more and more evident that man, like the rest of the living creation, is subject to the laws of heredity. Now, if we want a disease-resisting wheat or an intelligent sheep-dog, we *breed* them, and know that we cannot get them in any other way. We should not attempt to get them by manuring, watering, and generally tending a wild grass, or by well feeding and carefully training any mongrel dog. The result would be too uncertain, the chances of success much too remote. The study of heredity in man teaches us the same lesson. There are families in which some special ability is inherited from generation to generation (e.g. the Bach and Mendelssohn families, the Darwins, Cecils, &c.). On the other hand, there are many pedigrees which show the handing on of some defect.

Of course, human relationships are very complex, and it is difficult to know how much to attribute to environment and how much to heredity. But man has hardly begun to consider this, the biological point of view, whether in his own individual life or in his social activities. It is difficult to estimate how far-reaching would be the effects if we all became 'eugenically minded', eugenics having been defined as 'the science of being well born'. One fact is obvious—that the future depends on us, each one of us. However long the present species of mankind continues to exist on this planet, those men and women of the far-distant future will be the descendants of some of those alive to-day. If we have been fortunate enough to inherit from a good ancestry, we can see that we pass on that inheritance unharmed. People descended from a stock with a marked hereditary defect, such as insanity, epilepsy, mental deficiency, may well ask themselves if they have the right to hand on their strain to the future.

We scatter seeds with careless hand
And dream we ne'er shall see them more.
But for a thousand years
Their fruit appears
In weeds that mar the land
Or healthful store. (J. Keble.)

As citizens, too, it is surely our duty to examine all our social legislation, making sure that it does not favour the less gifted, less able, and less energetic members of the community so much that it discourages reproduction of the more richly endowed types, as some recent legislation has tended to do. It is obviously very dangerous for a nation to breed chiefly from its poorer stocks. While we must do our best for all our fellow men, we dare not sacrifice the future for the present. Until we have more knowledge, however, we cannot lay down any definite laws; the most that we can do, at present, is to set our faces in the right direction. Obviously we should value descent from a really good sound stock as an inheritance above price.

If your course in biology has interested you in these wider problems confronting humanity your work will not have been in vain.

CHAPTERS XXXI–XXXVII

SOME SUGGESTIONS FOR FURTHER READING

I. Reproduction, evolution, and heredity.

Animals in the Making. J. A. Dell. (Bell.)
How Animals Develop. (More advanced.) Waddington. (Murray.)
Six Talks on Heredity. Adams. (Heffer.)
Biology and Human Life. Gruenberg. (Ginn.)
The Coming of Evolution. Judd. (C.U.P.)
Evolution: Fact and Theory. Wells, Huxley, and Wells. (Cassell.)
What Darwin Really Said. J. S. Huxley. } (Routledge.)
From Monkey to Man. Buxton. }
Ancient Plants. Stopes. (Jack.)

II. General reading.

Life. Shipley. (C.U.P.)
Ways of Living. J. A. Thomson. (Hodder & Stoughton.)
Threads in the Web of Life. J. A. and M. P. Thomson. (Macmillan.)
The Living Body. Wells, Huxley, and Wells. (Cassell.)
The Animal's World. Mackinnon. (Bell.)
The Natural History of Some Common Animals. Latter. (C.U.P.)
Animal Life by the Seashore. Boulanger. (Country Life Series.)
Animal Life of the British Isles. Step. (Warne.)
Birds of Great Britain. Pycraft. (Williams & Norgate.)
Our Resident Birds and How to Know Them. } Elms. (Butterworth.)
Our Migrant Birds and How to Know Them. }
The Baby Bird and its Problems. Bickerton. (Methuen.)
Chats on British Mammals } Simpson. (Sheldon Press.)
More Chats on British Mammals }

APPENDIX I

SCIENTIFIC NOMENCLATURE AND THE CLASSIFICATION OF LIVING ORGANISMS

In this book the common or 'popular' names of plants and animals have been used, where such exist, to facilitate a first reading. They are, however, unsatisfactory for further study. Similar names are given to forms which have only a superficial resemblance; e.g. the *English bluebell* (Scilla nutans) is a monocotyledon, the *Scotch bluebell* or *harebell* (Campanula rotundifolia) a joined-petalled dicotyledon (cp. p. 347). Further, the same form may have many different names; e.g. *wild arum*, *cuckoopint*, *lords and ladies*, *jack-in-the-pulpit*, *calvesfoot*, *wakepintle*, *wake robin*, *starchwort*, *aaron*, are all local names in common use in different parts of England for the same hedgerow plant (Arum maculatum).

All confusion is avoided by the use of **scientific names**, which are the same in every language. The system of nomenclature now in use was introduced by Linnaeus (1707–78), a Swedish naturalist. Every organism receives a double name, one denoting the wider group or *genus* to which it belongs, the other the particular *species*, e.g. *Mucor mucedo* (the bread mould), *Rana temporaria* (the common frog), *Homo sapiens* (modern man). Organisms belonging to the same genus resemble one another closely in structure, e.g.:

Ranunculus acris	Meadow buttercup (cp. p. 450)	*Felis domesticus*	Common cat
Ranunculus repens	Creeping buttercup	*Felis leo*	Lion
Ranunculus bulbosus	Bulbous buttercup	*Felis tigris*	Tiger
Ranunculus ficaria	Lesser celandine	*Felis parduus*	Leopard
Ranunculus aquatilis	Water-crowfoot (cp. p. 277)	*Felis onca*	Jaguar

In both groups the structural resemblances are very obvious.

It is found that broader similarities exist even between genera; a group of related genera forms a *family*; e.g. Leguminosae (cp. pp. 457 and 462), Compositae (cp. p. 466). Families fall naturally into *orders*, orders into *classes*, and classes into *phyla*, as indicated on p. 527. Those who believe in evolution hold that such similarities of structure indicate a common ancestry (cp. p. 516):

Kingdom	*Phylum*	*Class*	*Order*	*Family*	*Genus*	*Species*
Animal	Vertebrata	Mammalia	Rodentia	Leporidae	[1]Lepus	L. cuniculus
Animal	Arthropoda (cp. p. 155)	Insecta (cp. p. 291)	Lepidoptera (cp. p. 460)	Pieridae	Pieris	P. brassicae
Plant	Thallophyta	Algae (cp. p. 83)	Phaeophyceae (brown Algae)	Fucaceae	Fucus	F. vesiculosus
Plant	Spermaphyta (cp. p. 19)	Angiospermae	Dicotyledonae (cp. p. 347)	Rosaceae	Rosa	R. canina

APPENDIX II

WELL-KNOWN HABITATS AND SOME OF THE COMMONLY OCCURRING PLANTS AND ANIMALS LIVING THERE

A. A hedge. This is planted by man to protect his fields, and consists of woody shrubs, often prickly ones (cp. p. 378) such as blackthorn, hawthorn, holly. The ground beneath is left undisturbed, and the hedge, once formed, soon becomes the home of many plants and animals for whom it provides shelter and food (cp. pp. 128–9).

Plants of the hedge.

(1) Various *trees and shrubs* are found, mixed with the original hedge plant; e.g. elm, yew, beech, hedge-maple, hazel, dogwood, privet, &c. These are often self-sown (cp. pp. 485–6).

(2) *Climbers* use the shrubs for support (cp. p. 379); e.g. bryony, honeysuckle, hop, convolvulus, rose, blackberry, cleavers, traveller's joy, ivy, &c.

(3) *Herbaceous plants* grow under the hedge, obtaining shelter and shade; e.g. stinging nettle, dead-nettle, dock, wild arum, violet, primrose, speedwell, stitchwort, cow-parsley, hedge-mustard, hedge-garlic, ground-ivy, &c.

Animals of the hedge.

(1) *Mammals.* Hedgehogs hibernate in the leafy litter below untrimmed hedges, but make their breeding-nests higher up, in the hedge itself. They feed on young birds, on insects, slugs, snails, earthworms, and similar food. Weasels, who climb the hedge as easily as they run over the ground, are another group of carnivorous hedge dwellers; they hunt such prey as mice, voles, and young birds.

Among the herbivorous mammals of the hedgerow are dormice, field-mice, and voles. The dormouse feeds largely on nuts, and hiber-

[1] This name is gradually being replaced, for historical reasons, by Oryctolagus.

nates low down in the undergrowth, in a protective nest of dead grasses. It makes its breeding-nest well above ground, often in a blackthorn bush. The field-mouse does not hibernate completely; although it is dormant during very cold weather, on mild days it comes out to feed. Another mammal which is almost ubiquitous is the brown rat; it is not a native, but spread from Asia into Europe in the sixteenth century, and reached Great Britain in ships coming from the Baltic. It eats anything and everything, even devouring its own kind. It can run, jump, and swim (cp. p. 529), is fierce, savage, and aggressive. It causes great damage—one estimate puts the loss to crops in Great Britain at £66,000,000 annually—and is universally detested.

(2) *Birds*. The hedge, especially when it has a southern aspect, provides cover and nesting-sites for innumerable birds, both resident and migrant (cp. p. 396). The song-thrush's nest is one of the first to appear (March). This bird feeds on animals provided by the hedge, on slugs, insects, earthworms, and the like, being particularly fond of snails. Robins, wrens, long-tailed tits, and hedge-sparrows are other familiar hedge-dwellers, all being insectivorous. It has been estimated that one tit will consume some 200,000 insects, in the form of eggs and larvae, annually. Among seed-eating inhabitants of the hedgerow are the yellowhammer and the chaffinch.

(3) *Other vertebrates* include snakes, lizards, frogs, and toads.

(4) *Insects and spiders* are perhaps the most conspicuous invertebrates, although snails, slugs, and other *molluscs* are also plentiful. The large vertical plate-like web of the cross or garden spider is a very common and striking feature of the autumn hedgerow, especially when it glitters with drops of dew. A little search will also reveal many hunting spiders (Lycosa and others, cp. p. 495), with their bags of eggs.

Among the insects are numerous butterflies and moths. The caterpillars of peacock and red admiral butterflies are found feeding on nettles, those of the painted lady on thistle leaves, of the brimstone moth on hawthorn and blackthorn, of the garden tiger moth (the so-called woolly bear) on dead-nettles. Beetles, glow-worms (whose larvae feed on snails), earwigs, flies—indeed insects representative of all groups (cp. p. 460)—abound.

B. A fresh-water pond. Wherever water accumulates on the earth's surface, aquatic creatures will be found. In any large pond we must distinguish between the inhabitants of the marshy zone round its edge and those actually in or on the water (cp. Fig. 29, p. 126).

Flora and fauna of the marsh and swamp.

(1) The commonest *trees* are willows and alders.

(2) *Herbs* grow in great variety, e.g. reeds, rushes, sedges (usually distinguished by a triangular stem), irises, marsh-marigolds, water-plantains, willow-herb (p. 480), water forget-me-not, water-mint, bur-reed, moneywort. Many marsh plants have rhizomes (cp. p. 369), by which they obtain a firm hold on the soft mud (cp. p. 279).

(3) *Mammals* of the marsh include the little water-shrew, which, like its brother of the hedgerow, is insectivorous; the water-vole (often called the water-rat), which sometimes makes its nest in an underground cavity near the pond's edge, at other times forms a platform of water-weeds which it anchors to the plants of the marsh. This platform can serve as a table as well as a support for the nest. The vole is essentially vegetarian; it drags water plants on to this 'dining-table', and then sits there to enjoy the juicy portions.

Along the borders of the larger pools the brown rat is often very abundant, even more so than the water-vole. It makes a somewhat similar platform of shortened rushes, on which the remains of its meals—fish-bones, birds' feathers, &c.—are often to be seen. Resembling the vole in appearance is the musk rat (musquash), an alien mammal with large webbed feet. A native of North America, it was introduced into England, and caused such damage that special measures were taken to exterminate it. A carnivorous inhabitant of fresh waters is the otter, which feeds largely on fish.

All these animals are thoroughly at home in pond and river, though, as might be expected, they do not breed in the water. They are good swimmers and divers, often remaining submerged for long periods with only the nose (cp. p. 311) breaking the surface of the water.

Finally, another mammal is often to be seen skimming low over the surface of quiet pools. This is Daubeton's bat (the water-bat), which seems to feed exclusively on caddis flies.

(4) *Birds.* Moorhens, dabchicks, and coots, many of the latter only summer visitors, nest among the rushes or on bushes overhanging the water. They are omnivorous, feeding on snails, worms, insects, and the like as well as on water plants. In winter siskins and redpolls visit the alders for their seeds. Other birds come to the pond to drink and to find insects; the pied wagtail, for example, which roosts among the reeds, or the marsh-tit, which so often builds its nest in a pollarded willow. Many of these birds can swim—e.g. water-rails, coots, moorhens, duck.

(5) *Frogs, toads, and newts* are all to be found on the marsh as well as in the water.

(6) *Many insects* live on the marsh plants. Feeding on willow leaves we find the larvae of the puss and swallow-tail moths, while those of the goat moth live on the wood, causing much damage to the tree.

Flora and fauna in the pond.

Many *plants* live in the water, their distribution depending largely on its depth (cp. pp. 83, 272, 275–7). In the shallows we find those with floating leaves, such as water-lilies, starwort, water-crowfoot; in the deeper water are many which are quite submerged (e.g. potamogetons, Canadian water-weed, &c. (cp. Fig. 79); others float on the surface, e.g. green algae of all kinds, duckweed, &c.

Of *pond animals* some live below the surface, e.g. fish; others (e.g. frogs, dragon-flies) are aquatic during a part of their life only. Many are aerial, using the surface film (caused by the tension between the water and the air above) either to facilitate movement over the surface of the pond (e.g. pond-skaters, water-gnats, water-crickets) or to hang suspended in such a way that air can reach their respiratory organs, e.g. gnats and mosquito larvae (cp. p. 313).

Among these *submerged animals* we find:

(1) *Fish*, e.g minnows, sticklebacks (whose interesting breeding habits should be studied), char, carp, pike, roach, eels (cp. p. 396).

(2) *Amphibia*, e.g. the young stages of frogs, toads, and newts.

(3) *Snails*, e.g. the great pond-snail (sometimes called the freshwater whelk), the wandering snail, the dwarf pond-snail; also many of the 'flat-coil' snails, such as the ram's horn, the whirlpool-trumpet and the keeled-trumpet snails. None of these are truly aquatic; they trap air in a space known as the mantle cavity and use it for respiration. Truly aquatic freshwater snails are the freshwater winkles (Paludina), which take up oxygen by means of gills (cp. p. 281).

(4) *Freshwater mussels*, the swan mussel, for example, which has gills.

(5) *Leeches* and other worms (cp. p. 291).

(6) *Water-spiders*. These, like the water-snails, are air-breathers (cp. p. 311).

(7) *Water-fleas, freshwater shrimps*, and other Crustacea, which use water for respiration.

(8) *Insects* often spend their early life in water, e.g. may-flies, whose larvae have structures for absorbing oxygen from the water; midges, who also obtain oxygen from the water; caddis flies, whose larvae

breathe by extensions of the tracheae known as tracheal gills, and who, directly they are hatched, form about themselves little protective cases of any material that may be to hand; gnats, whose life-story is told on p. 313; dragon-flies (cp. p. 315); stone and alder flies; beetles, e.g. whirligig beetles, the carnivorous water-beetle, &c.; they store bubbles of air which they use for respiration.

Careful search will reveal many more of these aquatic creatures; the student should examine a pond for himself.

C. A rock-pool (salt water). Conditions here are very different from those in a fresh-water pond. Not only does the water contain about 3 per cent. of mineral salts, but, while the one is still and calm, in the other all living creatures are exposed to the play of the waves and the unceasing rise and fall of the tides. Small wonder, then, that a very different flora and fauna flourish in such an environment. The *plants* here are algae (cp. p. 83): *green*, e.g. sea-lettuce; *brown*, e.g. fucus (cp. p. 431); *red*, e.g. the braided-hair seaweed, Dasya, &c. In general these are attached to the face of the rock and maintain their position in spite of tides, currents, and waves.

Many *sedentary animals* also hold on fast to the seaweeds or to the rock itself: sponges; hydroids, e.g. sea-hair, squirrel-tail; sea-anemones, e.g. beadlet, Dahlia; molluscs, e.g. periwinkles, limpets, whelks, mussels, &c.

Among more *active animals* are prawns, crabs (especially the shore crab), &c., and, finally, various fishes, the young (fry) of many deep-sea fish, as well as blennies, gobies, rocklings, sucker-fishes, &c., some of these latter being only feeble swimmers. Certain fish can live both in fresh and in salt water (cp. pp. 395–6), but usually they are either fresh- *or* salt-water animals and are confined to the one medium.

There is a marked contrast between a rock-pool and a fresh-water pond. Creatures depend for their existence on a suitable environment, and each one can only thrive in those external conditions to which it is adapted (cp. pp. 124–9). This truth is very clearly illustrated by any study of ecology.

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